JULY 1952

Chemical Engineering Progress

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Chemical Engineering Progress

Volume 48 — JULY

Number 7 — 1952

CENTENNIAL OF ENGINEERING 1852 1952

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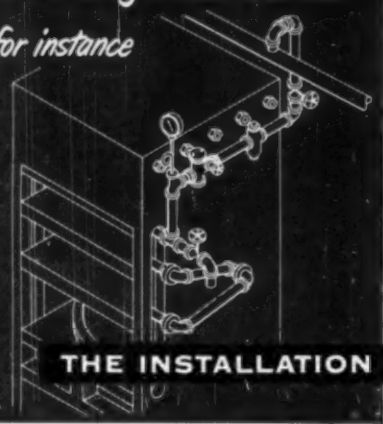

THE INSTALLATION

Crane Brass Pressure Regulators on steam lines to rubber molding presses; Dryden Rubber Division, Sheller Mfg. Corp., Chicago. 225 units in service.

THE HISTORY

Steam generated at 130 psi is reduced through individual regulators on molding presses. Pressure used at machines is 60 to 100 psi depending on work. Features of regulator service needed most are: (1) non-fluctuating outlet pressure automatically maintained within close regulation; (2) easy adjustment by press operator to specified pressure for given work.

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FEATURES:	Equally good on steam or air
SUITABILITY:	Steady outlet pressure - no drift
MAINTENANCE COST:	Routine servicing only
SERVICE LIFE:	Many installed more than 25 years — Still O.K.
OPERATING RESULTS:	Fully automatic steam control at lowest cost
PRICE:	Good Buy - has no equal
AVAILABILITY:	Stock item in Crane Line

THE VALVE

Crane No. 960 Brass Pressure Regulators reduce steam or air pressures up to 250 psi, to within 80% of inlet pressure. Factory pre-set to operate within any of 4 ranges from 1 to 200 psi, with easily selected service pressure within set range. Precision made; fully automatic; highly dependable, even under reasonable fluctuation of inlet pressure. All wearing parts renewable. See your Crane Catalog or Crane Representative for full data.

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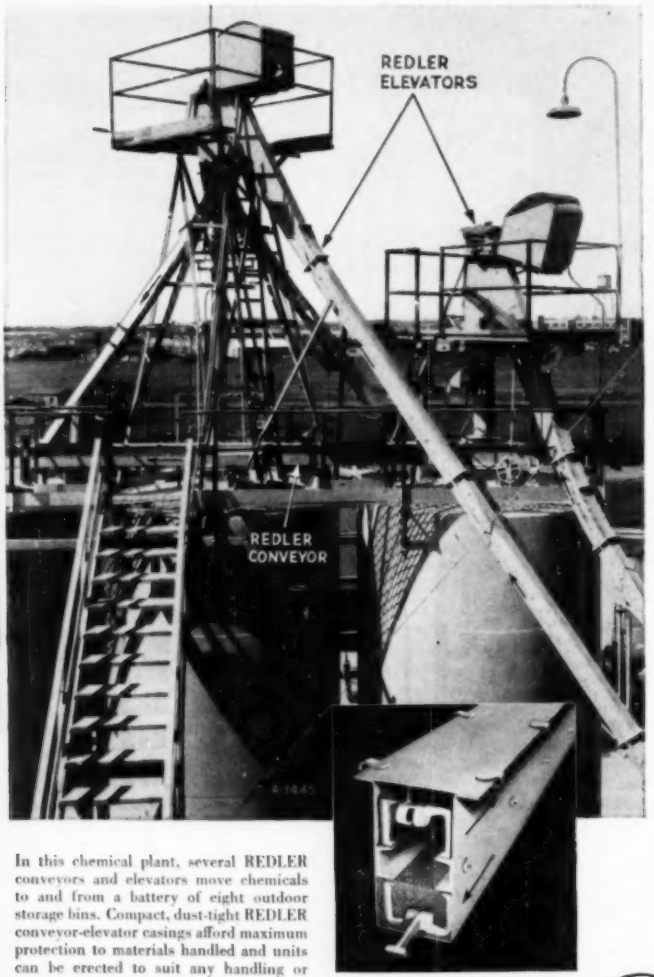

In this chemical plant, several REDLER conveyors and elevators move chemicals to and from a battery of eight outdoor storage bins. Compact, dust-tight REDLER conveyor-elevator casings afford maximum protection to materials handled and units can be erected to suit any handling or storage requirements. Section view through REDLER conveyor at right, shows how materials move within its totally-enclosed casings.

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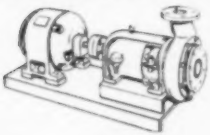


❶ I-R Chemical Pumps are Armored against Corrosion with IRCAMET

These Ingersoll-Rand chemical pumps are built to stand up under the continuous handling of corrosive and abrasive liquids. All parts of the pump that come in contact with the liquid are made of IRCAMET – a high nickel-chromium-molybdenum alloy steel developed exclusively by I-R for chemical pump service. Laboratory tests and years of field experience have proved its exceptional ability to resist the corrosive action of a wide variety of acids and alkalis. Other materials are available for special operating conditions.

In the complete line of I-R chemical pumps, you'll find a unit that's *right* for practically any application . . . a pump that is completely engineered for maximum performance, minimum maintenance, and high operating efficiency. For complete information, write to Ingersoll-Rand, today, asking for Bulletin 7095. Or, if you have a special pumping problem, contact your nearest I-R engineer. He will be glad to help you.

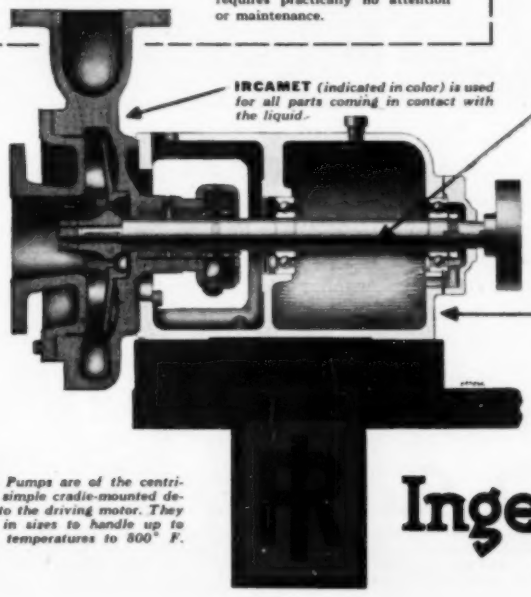
❷ They are PROTECTED AGAINST LEAKAGE —with the *LEAKOLLECTOR*

The patented LEAKOLLECTOR stuffing-box gland – an exclusive feature of all I-R chemical pumps – provides a simple and effective solution to the problem of pump leakage. It completely encircles the stuffing box, trapping all leakage so that it can be drained away for collection or disposal. The split gland is accurately fitted to both the inside and outside of the box, and will catch any seepage escaping between the shaft and packing, or between the packing and the bore of the box. The LEAKOLLECTOR is easily removed from the shaft for repacking the box.

❸ They are BUILT FOR EASY MAINTENANCE —and *LESS OF IT*

These pumps are ruggedly constructed to last longer on the job—and the simple design, with all parts easily accessible, means less "time out" for maintenance. The short, rigid stainless-steel shaft prevents impeller whip and eliminates many stuffing box troubles. The suction nozzle is removable, permitting access to the impeller without disturbing the discharge piping.

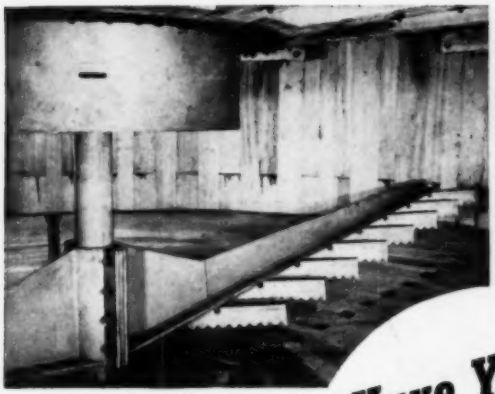
The CAMERON SHAFT SEAL can be installed on all I-R chemical pumps to replace the conventional stuffing-box packing. It eliminates stuffing-box leakage and requires practically no attention or maintenance.


IRCAMET *(indicated in color) is used for all parts coming in contact with the liquid.*
STAINLESS STEEL SHAFT *provides maximum strength, plus high corrosion resistance.*
PANOFLAM, *a modified, synthetic, resin-base paint, highly resistant to chemical action and to oil and grease, forms a protective coating over the entire unit.*

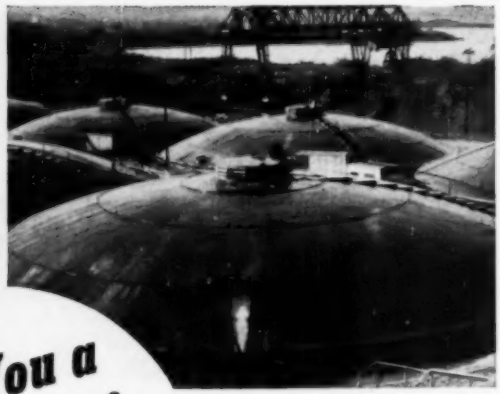
I-R Chemical Pumps are of the centrifugal type, of simple cradle-mounted design, coupled to the driving motor. They are available in sizes to handle up to 4000 gpm at temperatures to 500° F.

Ingersoll-Rand

CAMERON PUMP DIVISION 362-10
11 BROADWAY, NEW YORK 4, N. Y.



Closeup of a special Dorr Tray Thickener with rubber covered mechanism and serrated rake blades. Lead covered steel, wood and stainless steel units have also been fabricated.

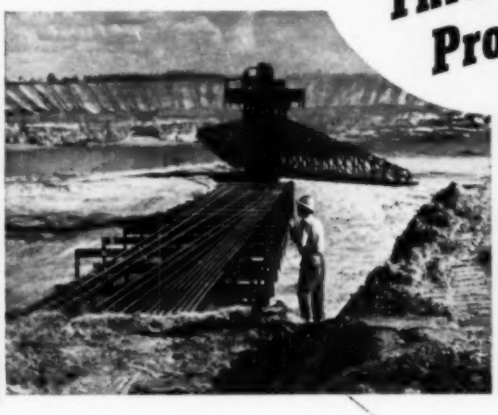


Dorr Thickeners are covered with concrete domes to minimize ammonia loss in a nickel leaching plant. Covered Dorr Thickeners are also used in the pigments industry where size precludes indoor installation.

Have You a SPECIAL Thickening Problem?

A special 300 ft. dia. Dorr Thickener equipped with picket arms and a flocculating feedwell installed in a 750 ft. dia. earthen basin clarifies 15,000 gpm of phosphate rock tailings.

One of the largest water recovery plants in the east uses three 250 ft. dia. Dorr Torq* Thickeners installed in a single earthen basin. Almost 5 acres of surface area is provided with a capacity of 14½ million gallons per day.



Many thickening problems in the process industries can't be solved by standard methods. It's here that Dorr's ability to provide a special unit, tailor-made for the special job, pays dividends. Here are four recent examples. If your problem requires a fresh approach, why not check Dorr . . . the oldest manufacturer of sedimentation equipment . . . *with the newest ideas.* Write for your copy of Bulletin No. 3001 "Dorr Thickeners for chemical, metallurgical and industrial processing." The Dorr Company, Engineers, Stamford, Connecticut.

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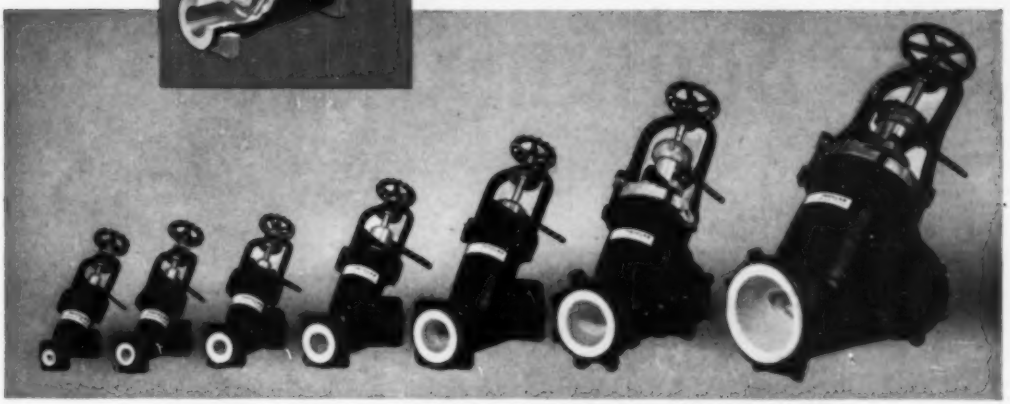

Y-Valves, as shown, and Angle Valves are available in Lapp TUFCLAD Chemical Porcelain in ½", 1", 1½", 2", 3", 4" and 6" sizes. Also safety valves, flush valves, plug cocks, pipe and fittings (to 8" dia.) and special shapes.

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PULSAFEEDER CHEMICAL PROPORTIONING PUMPS

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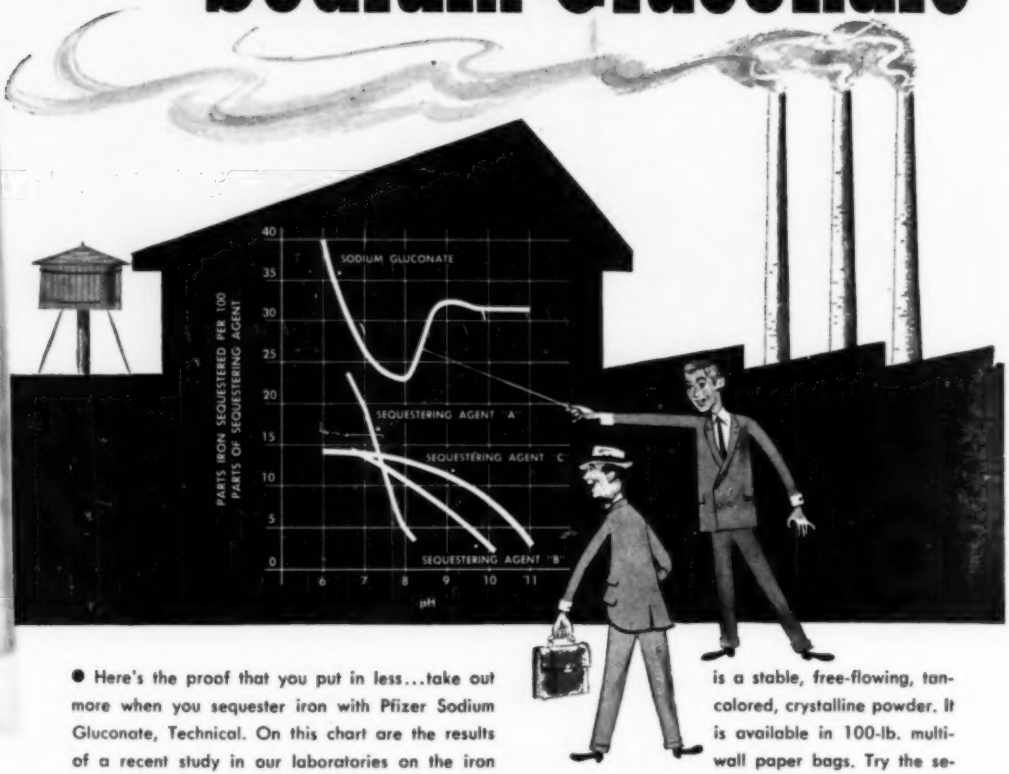

● Here's the proof that you put in less...take out more when you sequester iron with Pfizer Sodium Gluconate, Technical. On this chart are the results of a recent study in our laboratories on the iron sequestering power of various sequestering agents. Of the four chemicals on the chart, you will note that Sodium Gluconate exhibited by far the best results in sequestering the ferric ion over a wide range of pH. Pfizer Sodium Gluconate, Technical, is a stable, free-flowing, tan-colored, crystalline powder. It is available in 100-lb. multi-wall paper bags. Try the sequestering agent with proved results. "Put in *less sequestering agent*...take out *more iron*"...with Pfizer Sodium Gluconate, Technical. Contact Pfizer today for more detailed information about this study. Call or write:

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Girdler Process News

GIRDLER DESIGNS AND BUILDS

new synthetic nitrogen fertilizer plant for Mississippi Chemical Corporation

Mississippi Chemical Corporation assigned complete responsibility for engineering and construction of its new integrated plant to one experienced source . . . The Girdler Corp. Original cost was lower than estimates from other sources, and also ammonia, nitric acid, and ammonium nitrate are now produced with a lower unit energy input than in any other similar plant.

The plant is a complex one, involving production processes for hydrogen, nitric acid, ammonium nitrate, etc. This is one of the few high-pressure, catalytic-process ammonia plants in the U. S. Methods for safe handling of gases at pressures up to 15,000 pounds per square inch had to be worked out.

Girdler has broad experience in handling such complete "process packages". . . covering design and construction of process plants involving very high operating pressures, high temperature reactions, and corrosive substances.

Call on Girdler in the planning stages of *your* processing facilities . . . you can do so with confidence.

The GIRDLER Corporation

LOUISVILLE 1, KENTUCKY
Gas Processes Division

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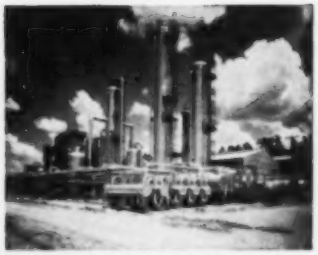
VOTATOR DIVISION: *Processing Apparatus for the Food and Chemical Industries*
THERMEX DIVISION: *Industrial High Frequency Dielectric Heating Apparatus*



Synthesis gas plant

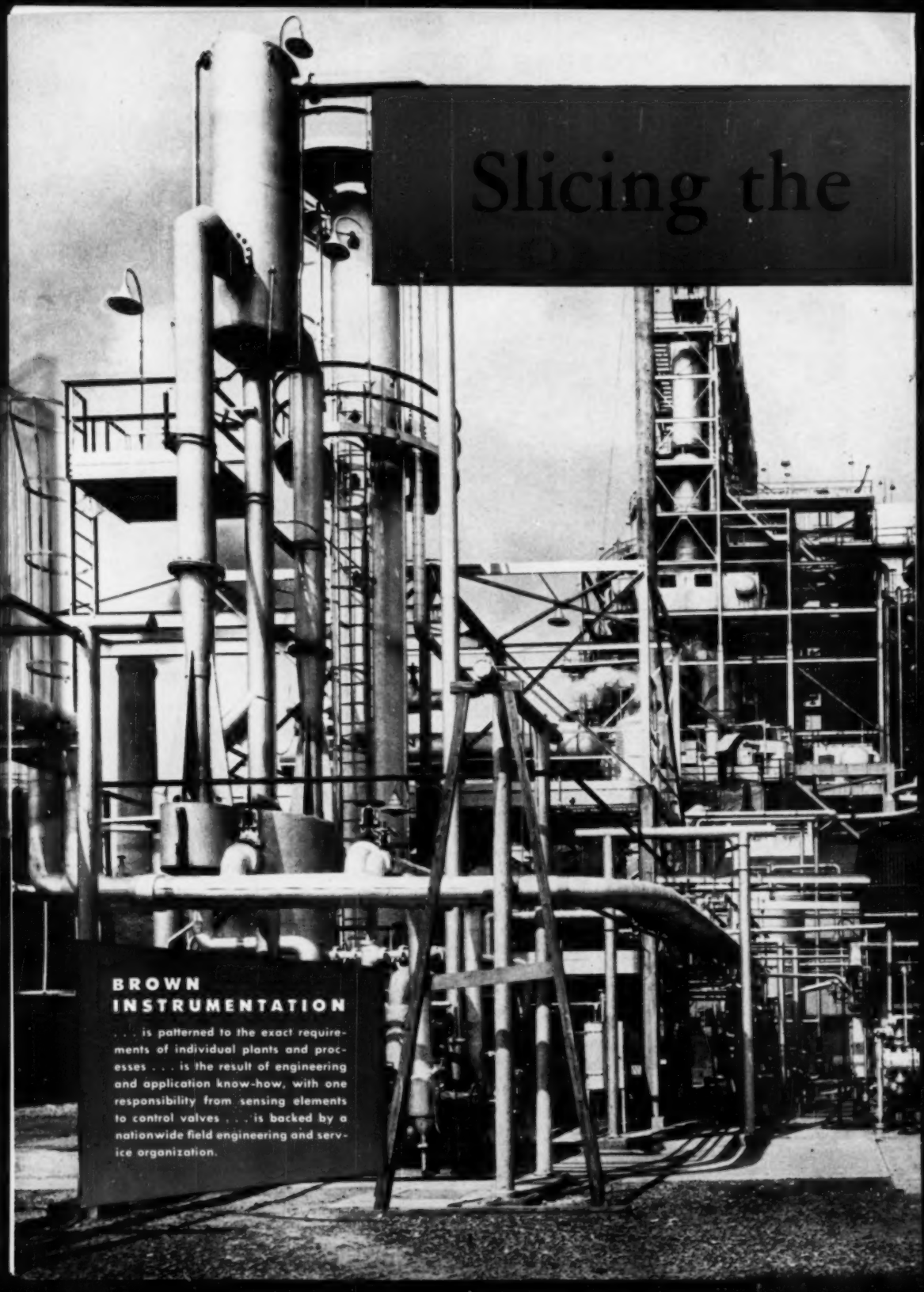
This unit at Mississippi Chemical Corporation manufactures high purity synthesis gas needed for the production of ammonia. Natural gas is the primary raw material. Superheated steam, used in the synthesis process, is produced by integrating steam generation with process functions. Thus the cost of a separate steam plant was saved.

Prilling tower

Final step in production of ammonium nitrate. The complete plant has various improvements in design and layout, and process combinations never before used. Proper coordination of countless details by Girdler was a major factor in low first cost of plant.

Want More Information?

Girdler's Gas Processes Division designs and builds plants for the production, purification, or utilization of chemical process gases; purification of liquid or gaseous hydrocarbons; manufacture of organic compounds. Write for Booklet G-35. The Girdler Corporation, Gas Processes Division, Louisville 1, Kentucky. District Offices: San Francisco, Tulsa, New York. In Canada: Girdler Corp. of Canada Ltd., Toronto.


Slicing the
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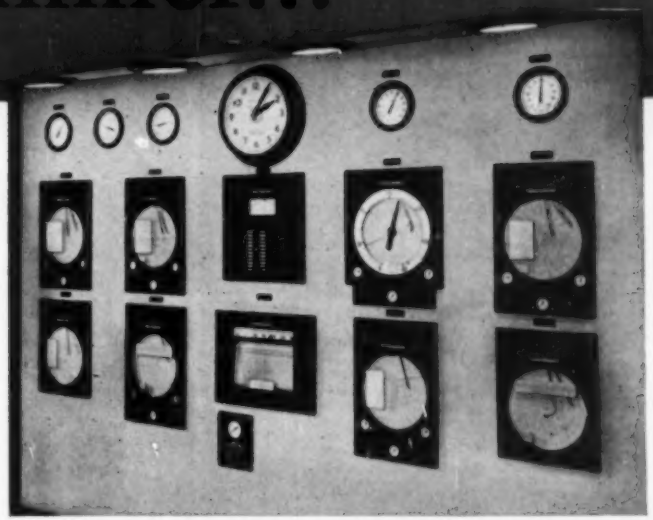
. . . is patterned to the exact requirements of individual plants and processes . . . is the result of engineering and application know-how, with one responsibility from sensing elements to control valves . . . is backed by a nationwide field engineering and service organization.

cuts thinner...



Deethanizing unit for fractionation of liquefied petroleum gas at Sinclair Refining Co. is regulated by Brown Instruments (at right) on factory-assembled panelboard.

with the help of
Brown Advanced Instrumentation

ACCURATE, coordinated control of fractionation is proving the key to economical separation and purification of chemicals, and to the efficient recovery of light ends of petroleum for conversion to liquid petroleum gas and petrochemicals.

Typical of modern fractionation is the LPG plant of the Sinclair Refining Company at Marcus Hook, Pa. Here as in thousands of operations throughout the world, Brown Instruments measure, record and control every variable critical to process efficiency . . . holding each in line with the precision essential to top output and quality.

When you're looking for automatic recording and controlling instruments for your fractionating operation, or *any other process, consider first:*

- The Brown know-how developed through many years of application experience in the industry.
- The completeness of the Brown line—recorders, controllers, panelboards, valves and accessories.

For a detailed discussion of your process requirements, call in our local engineering representative . . . he is as near as your phone.

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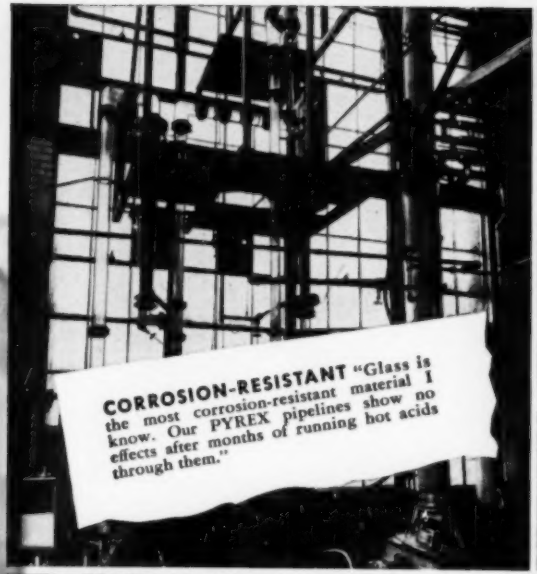
First in Controls

● *Important Reference Data*

Write for Composite Catalog No. 5000 describing the principal Honeywell instruments for process industries.

Why more chemical processors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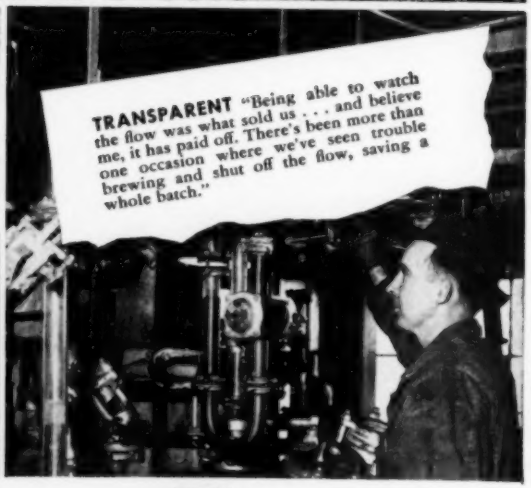
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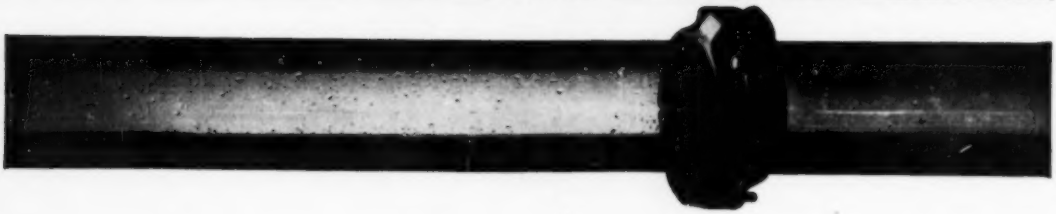

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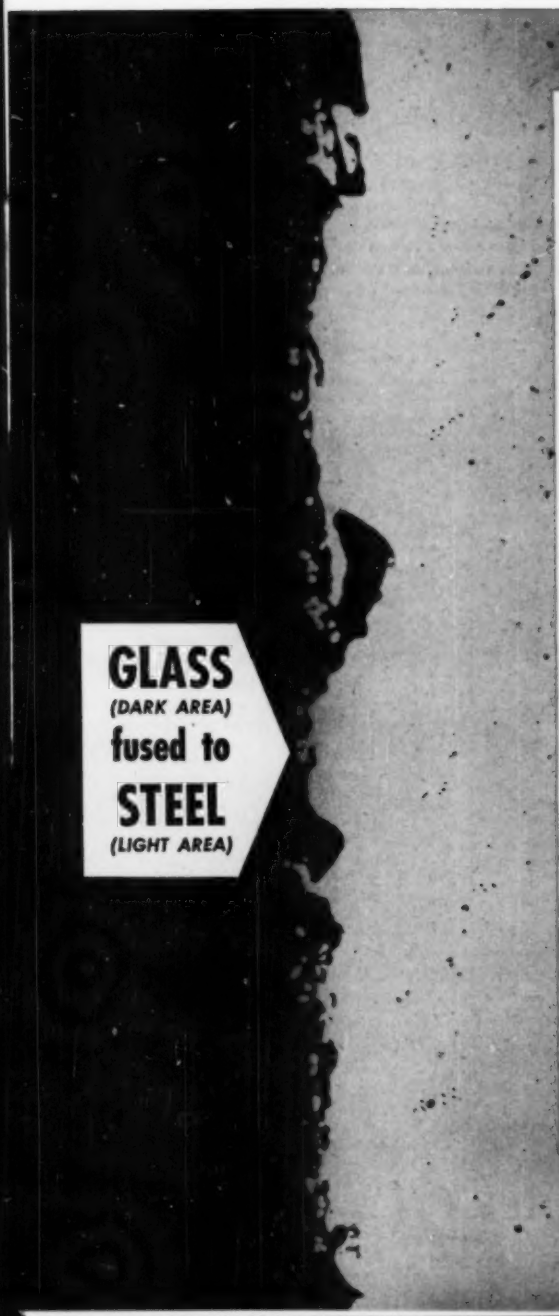

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OPINION AND COMMENT

CIVIC RESPONSIBILITIES OF THE ENGINEER

A PROFESSOR of chemical engineering in one of our larger universities recently criticized company representatives who were interviewing students, because they were emphasizing too greatly the employee benefit programs which their companies offer the prospective employee. The complainant contended that less emphasis should be placed on what the new employee might expect to receive and more emphasis should be placed on how the young professional's assets could be converted into real service to his employer. Aren't we all guilty to some degree of looking at our job and at life in general in terms of what we are going to get out of it rather than of what we can put into the development of our employer's business and what contribution we can make to the welfare and happiness of our fellow-men? Too many of us unconsciously become self-centered. It has been said that "a person wrapped up in himself makes a very small package." By looking out for the welfare of others instead of, or at least in addition to, one's own welfare, a person will not only make the world a better place in which to live but also will be happier himself.

It should be remembered too that the man with university training, be it in chemical engineering, law, or medicine, has been given not only a "kit of tools" but a responsibility to use it for the betterment of society, of which he is an important part. He should take a place of leadership in the community in which he lives. His fellow-citizens who have not had the good fortune to obtain a college education look to him for leadership and they have a right to do so. The Biblical parable of the talents applies to the chemical engineer of today as truly as to the servants in the parable. We who have special talents, whether natural or acquired through university training, owe it to society to use those talents for the benefit of others.

The leadership of which we speak does not necessarily involve holding an important office in a service club, charity drive or church organization but may merely involve using one's influence as a plain, hard-working citizen to further the things that are worth while in the community. Speaking publicly for decency and honesty in government, urging fellow-citizens to exercise their voting privileges, organizing a group to build that community playground, and ringing doorbells to obtain signatures on a petition to secure some community improvement, all involve time and often downright hard work; but the satisfaction which comes from accomplishing something of value to one's community makes the effort distinctly worth while.

We often tend to belittle our influence with others and do not speak out when we should. Our training as engineers gives us the ability to analyze available facts, to determine whether more facts are needed and to decide from the facts what course of action should be taken. Others, not trained as we have been, are more likely to be swayed by emotions and form conclusions hastily. It is our responsibility to use our analytical minds to reach sound conclusions and then use our efforts to influence others to form similar conclusions. Our judgment is respected and expected.

It is said often that man would not be happy if he couldn't gripe. We as citizens gripe about corruption in Washington, but do we ever write our congressmen to let them know our sentiments? Few of us ever do. Congressmen say they appreciate receiving opinions of their constituents and I believe they are sincere in this. If every member of the Institute once or twice a year would write to each of his congressmen on matters of vital concern to him as a citizen, the combined force of such actions would have a marked effect on the trend of much legislative action in Washington. Let's quit the griping and do something constructive!

Most companies are proud of their technical men and like to see them take places of leadership in the community. Few companies indeed begrudge a reasonable amount of time away from company business to discharge important civic duties which cannot be attended to outside of business hours. Participation by employees in civic affairs makes for good public relations. Management is coming to recognize this in increasing degree.

One contribution which the chemical engineer can make to the life of the community is to participate in promoting vocational guidance of young people. Too many young people in high school hesitate to go to college because they know little or nothing about opportunities and personal qualifications necessary for success in different fields or professions. Enlightenment along this line by a team of university-trained people, of which a chemical engineer might well be a member, would be eagerly welcomed by most sincere young high school students. Many high school students pick a university course because it was the one in which their favorite uncle or a family friend majored and because he was successful in his chosen profession. The student may have little aptitude or few personal qualifications for such a profession. Most chemical engineers could render invaluable assistance in this field of vocational guidance.

Although we have discussed this subject in the light of professional responsibility, it should be considered also as personal opportunity. If we as individuals can leave this world a trifle better for having lived in it, life will truly have been worth living.

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WHITHER CHEMICAL ENGINEERING SCIENCE?

Chemical engineering, like other sciences, is undergoing radical, if not revolutionary, changes. . . . Unit operations, once identified as separate fields of endeavor, are gradually becoming, with the continual discovery of underlying principles, general formulations of engineering experience. . . . In the following pages seven noted and thinking engineers point up present trends in chemical engineering and prognosticate its future as a science and an art. . . .

AN ART AND A SCIENCE

GEORGE GRANGER BROWN

University of Michigan, Ann Arbor, Michigan

GEORGE GRANGER BROWN, Edw. DeMille Campbell University Professor of Chemical Engineering and dean of engineering, University of Michigan, was associated at one time with the New York Edison, Aluminum Company of America, and the Union Special Machine Co., the National Dairy Products, Inc., and has been a consulting engineer for thirty years. A Ph.D. from the University of Michigan, he has been on the staff of the department of chemical engineering since 1920. Dr. Brown, the author of "Unit Operations," has been a Director of A.I.Ch.E. (1939-42), Vice-President (1943), President (1944), and chairman of many Institute committees including Constitution and By-Laws, and Education and Accrediting. He received the William H. Walker Award in 1939 and the Hanlon Award of the Natural Gasoline Association of America in 1940. In 1950 he served as director, U. S. Atomic Energy Commission, division of engineering.

A GENERAL agreement exists—even among six rather different individuals—that engineering may be regarded as the art and science by which the properties of matter and the sources of power in nature, are used by man in structures, machines, and manufactured products. Agreement in this, however, was just on Noah Webster's say-so. The definition implies that the application of this science will accomplish some particular objective and is therefore useful.

But actually, what is engineering science? Science is defined as the accumulated and accepted knowledge which has been systematized and formulated with reference to general laws. Putting these two concepts together, the conclusion can be drawn that the phrase *chemical engineering science* signifies that deposit of knowledge which has been systematized or formulated for use by the chemical engineer in the practice of his profession. However, it is generally accepted as a workable theory that no particular method of collecting chemical engineering data could or should be adopted by all chemical engineers; that the methods depend upon the available information and any system must be flexible if it is to be of continuous service. This is clearly evident in the evolution taking place regarding the classification of the unit operations.

Since in these comments the phrase *chemical engineering science* is preceded by the word whither, we are committed to a discussion on the future method for arranging or codifying the aforementioned knowledge which will be used by the chemical engineers. This presupposes a considerable amount of crystal-ball gazing but out of it may come some indication or some encouragement as to better ways for grouping this correlative matter.

KNOWLEDGE BASIC TO CHEMICAL ENGINEERING

J. C. ELGIN

Princeton University, Princeton, New Jersey

J. C. ELGIN, professor of chemical engineering, chairman of the department, and associate dean of the Engineering School, Princeton, N. J., has been engaged in a consulting capacity in the fields of plastics, rubber, petroleum, and textile processing, and as a consultant for A.E.C. Professor Elgin, a Director of A.I.Ch.E., (1947-49, 1952-55), has served on many committees including Admissions, Constitution and By-Laws, and as representative on National Research Council. He was engineering assistant to associate director, division chief, and consultant, S.A.M. Labs, Manhattan Project, Columbia University, 1944-45.

WITH a view toward the future status of chemical engineering, I like to think for convenience, of a chemical manufacturing process broadly divided into two zones—a chemical reactions zone and a separations zone. Material and products must be transported to and from each and must be mixed and agitated in each. Energy must be added to each and heat added and removed. Fluid mechanics, dynamics and transportation, heat flow, material, energy and heat balances, and the physical or thermal quantities that enter into these, therefore comprise knowledge which is basic to chemical engineering and design.

In the chemical-change zone, a complex combination and series of many processes simultaneously proceed as follows: mixing, physical solution, and precipitation and chemical reactions. Chem-

ical-reaction rates, mass-transfer rates, fluid motion, and heat-transfer rates are combined. Governing factors are chemical equilibrium, treated through chemical thermodynamics, chemical kinetics combined with kinetics of mass and heat transfer—that is, chemical engineering kinetics—mechanics of fluid flow, fluidization and mixing. These principles and their combination into design procedures, should therefore constitute the subject matter around which this zone is organized.

The processes taking place in the separations zone are likewise accompanied by the addition of power and the addition or the removal of heat. They can be regarded as divided into two classes—mechanical separations and phase-change separations. The former may occur by the force of gravity, by centrifugal force, or by straining through a semipermeable medium of some type, and involve essentially, aspects of fluid mechanics. The latter, phase-change separations, all rest upon the same basic principle, namely, the creation of a second phase—of two new phases in some cases—and distribution of the feed components between this phase and that in which the components to be separated were originally present, followed, of course, by subsequent separation of the two.

Any combination of the three possible phases, liquid, solid, gas or vapor, can theoretically be used. Even two gaseous phases can be involved if they are separated mechanically by a semipermeable membrane as in gaseous diffusion. All these phase-change-separation processes can be treated in terms of the same fundamental laws and have the same basic principles and design theory, and these can be generalized irrespective of the particular properties of the phases. The application of material and heat balances is the same. The basic contacting techniques are the same in principle and characteristics for each.

Continuous countercurrent multistage, or continuous differential contact, application of reflux, enriching and stripping operations, have the same significance and design principles whatever the physical properties of the phases.

Phase equilibrium, its representation and principles, can be generalized, treated, and interrelated through thermodynamics, for any combination of phases. Forces operative in a spray tower, in a bubble tower, in a bed of fluidized solids, in sedimentation, in pneumatic transport, are basically the same whether it is masses of liquid, solid, or gaseous particles that are flowing. An analogous situation can be visualized for film-type contacting.

Contacting techniques and their theories—phase equilibrium, mass transfer, combination of these into design procedures and principles, and the mechanisms and dynamics of phase contacting and separation—are the basic principles involved. These should constitute the framework for the separation zone, and not a system built on a particular combination of phases.

It is broad principles, such as these indicated, around which chemical engineering science should be systematized in the future, if chemical engineering is to continue its advance.

CLASSIFICATION OF ESSENTIAL SCIENCES

KARL H. HACHMUTH

Phillips Petroleum Company, Bartlesville, Oklahoma

KARL H. HACHMUTH was graduated from the University of Michigan with a B.S. degree in chemical engineering. He spent his first professional years working in manufactured-gas plants and as a development chemist for the Ozokerite Mining Co. He joined the Phillips Petroleum Co. in 1927 as a chemical engineer, serving successively as research engineer, group leader, section chief, associate director of research, technical consultant in chemical engineering, and member of the Research Planning Board, which position he now occupies. Hachmuth is known for his contributions to phase equilibria, thermodynamics, and the mathematical analysis of chemical engineering problems.

THIS outline on the basic sciences necessary for practicing chemical engineering can serve to illustrate the present status of chemical engineering sciences and thus suggest those places where attention should be directed and where the most likely advances will be made in the immediate future.

The essential scientific subjects or divisions of science used in the chemical engineering field are:

Mathematics
Stoichiometry
Thermodynamics
Reaction Kinetics
Material Transfer
Energy Transfer

This list can be lengthened by including less frequently or extensively used material, but none of the divisions can be left out without sacrificing an adequate scientific background for the practice of chemical engineering.

Mathematics is in a different category from the other subjects in this list. For it is a tool used in the application of the other subjects to a given problem and so it must be used. By itself, it is meaningless as far as engineering is concerned. Each of the other divisions of science can be applied individually to obtain useful information on any chemical engineering problem, although a complete solution requires simultaneous application of all the divisions.

Stoichiometry teaches the ideal proportions of the reactants required, and the compositions and amounts of the possible products and by-products.

Thermodynamics reveals the maximum extent of reaction that may be hoped for including the effects of temperature, pressure, etc., on this maximum, as well as giving the minimum quantity of energy exchange required to carry out the desired process.

Reaction kinetics tells how fast reactions will proceed provided the material-transfer rate and energy-transfer rate do not limit the process by their relative slowness.

An adequate knowledge of all these factors is necessary for successful process design and operation. Too often those familiar with laboratory-scale experiments neglect to give sufficient consideration to one or more of the rate factors because those factors may have no important effect on small-scale operations.

That is, briefly, an outline of the things I think of as classifications of science or the sciences which are essential in chemical engineering. To illustrate a bit: All distillation or separation processes are fundamentally similar as are the solutions of the problems attendant on these processes. But, in order to obtain practical solutions in a reasonable length of time, simplifying assumptions are made. This results in three types of problems with corresponding types of solutions. In some separation processes, approach toward equilibrium is rapid and the assumption of stepwise attain-

ment of equilibrium gives good approximations of actual performance. In other processes the rate of material transfer between the phases is slow so that the two phases never approach equilibrium. Design calculations must be concerned then with material-transfer mechanisms and rates. Where separation processes involve chemical reactions, even weak, easily reversible reactions, the reaction rate may be the most important factor in design estimations. If a rigorous solution is desired, all the classifications of science, including rate of energy transfer, must be used to analyze the problem and all separation problems, in fact, all chemical engineering problems become similar and solvable by a limited number of basic concepts. Only in simplified solutions, used because of time-saving, or because much of the needed information is lacking, do chemical engineering problems appear to require multitudinous special techniques.

This concept, namely, that chemical engineering science consists of a few basic principles, can and probably should be used to judge the present status of chemical engineering science, to choose fields that need more emphasis, to predict where greatest advances can be made, and to build training programs that are more efficient and generally useful.

THE SCIENTIFIC ASPECT OF CHEMICAL ENGINEERING

R. L. PIGFORD

University of Delaware, Newark, Delaware

R. L. PIGFORD, consultant to industrial chemical companies in unit operations, is at present chairman, department of chemical engineering, University of Delaware, Newark, Del. He was active in wartime research work for the U. S. Army Chemical Corps and National Defense Research Committee. He received a Ph.D. in chemistry from the University of Illinois. For six years he was associated with Du Pont at the Engineering Research Laboratory, Experimental Station. He has been active in the A.I.Ch.E. doings, especially on the Program Committee.

THIS writer subscribes to the viewpoint that a real and thorough understanding of scientific principles is a necessary part of a chemical engineer's professional equipment. Classified organization of the subject matter covered in the usual college curriculum, while important, is only one phase of the problem of education for applied science. A more general viewpoint may be that chemical engineers should broaden rather than limit their background of basic science, as otherwise they may be poorly equipped fifty years hence to "handle unfamiliar problems intelligently," as W. K. Lewis once described the goal of education. In fact, one point that we should emphasize is that in order to do our jobs well we should not hesitate to accept an assignment in whatever field of applied science may be required.

This discussion will touch on some of the personal qualifications of the chemical engineer that can and should be cultivated, and which will enable him to perform more effectively and efficiently as his work develops.

I have noticed the recent trend of classifying all engineers in one group, in the societies of professional engineers. In these societies the members are not designated by their particular field of interest. This, I think, is generally a good idea. But it seems that chemical engineers have some peculiar characteristics and this author is inclined to think they ought to stress these peculiarities instead of just becoming deadwood in a group of the engineering professions.

These individual characteristics inherent in the chemical engineer ought to be developed. Let me make it clear, however, at the start, that I do not agree with the comments leveled at chemical engineers, namely, that they are all research engineers. I don't think they are nor do I believe that the attitudes which have been developing in chemical engineering teaching and in the professional practice of chemical engineering, are exclusively in the field of research. On the other hand, one of the finest things about the chemical engineering tradition is that we are quick to bring basic principles of physics and chemistry to bear on our various problems instead of adopting the "handbook approach."

It is clear, I think, to all of us, that these problems are becoming more and more unusual and unexpected. Our ability to handle such problems with confidence is to a large degree a measure of our success as a profession. This quality is what the chemical engineer should try to develop, and to effect this change—for change it undoubtedly would be—there must be a deeper and broader appreciation of scientific facts instead of an on-the-surface, narrow one. This is in distinct contrast to that association of idea carried in the words *art of engineering*. At times these words imply the handbook approach. This should be avoided, as a step forward in handling unexpected situations with confidence. Instead of having to pull out our handbooks, we should be able to do a decent job on a problem before us with just the basic scientific principles that each chemical engineer carries in his mind.

Now there are some other peculiarities of chemical engineering that the chemical engineer should try to emphasize. We've inherited the philosophy of experimentation from the chemists. I don't think there is any other branch of engineering that indulges in experimentation to the extent the chemical engineer does, and this is one of our strengths, one of the capabilities we should increase, if possible.

Considerable effort is being spent on purely physical problems of physics rather than of chemistry. Here is the place where we differ and depart from the chemists and this accounts for one of our peculiar strengths. In contrast with the equipment that the chemist has, we have some knowledge of chemistry and, in addition, the ability to handle certain physical problems.

Therefore, we should continue to take the attitude that the whole field of applied science is open to the chemical engineer. I think he should not hesitate to do the best job he can on the problems that are fundamentally his—the problems of the chemical or allied industries—regardless of what field of scientific knowledge he may be led into. I think he should not hesitate to do a decent job on the problem of metallurgy if that is necessary. In years past, physicists and physical chemists, who are closely akin to us in their fields of interest, worked on many problems that today are discussed in our own literature almost as often as in the literature of chemistry and of physics. As a matter of fact, physical chemists and physicists are turning to new fields of endeavor that are just opening up. Perhaps by

forfeit, we have been left with a field of experimentation and of science which will not be developed properly unless it is developed by chemical engineers. Think, for a minute, of the problem of selecting an effective solvent for an extractive distillation job. It is really the properties of the solutions that are at the heart of the whole thing. Why should we hesitate to go into the field of physical chemistry involving solutions —not molecules, mind you—but the macroscopic viewpoint of solutions if that is what we need in order to select the best, the most efficient, and the most economical solvent for an extractive distillation job. We shouldn't hesitate to undertake this job. We should feel it is ours as much as it is that of the physical chemists.

Many physicists and physical chemists are interested today in learning more and more about less and less. This is fine, I am sure. I doubt if we should have had the atom bomb if it had not been so. But in spite of this, we should realize that there remains in these fields a region in which we should be active. We have actually done some effective work already on basic problems of this kind. For example, the construction of compressibility factor charts in order to estimate fluid properties more readily and more generally than by other techniques was a significant contribution. Had it not been for our attitude toward developing physical chemical tools for maximum use in industry, we would not have gone as far as we have today.

The principal point is that in the future we should try to develop our general understanding of scientific principles, including chemistry, physics, physical chemistry, mechanics, even better than we have been able to do so far.

THE EDUCATED MIND

J. H. RUSHTON

Illinois Institute of Technology, Chicago, Illinois

J. HENRY RUSHTON, professor of chemical engineering and director of the department, Illinois Institute of Technology, is also associated with the Mixing Equipment Co. as director of research. His teaching experience has included periods with the universities of Michigan and Virginia. As an A.I.Ch.E. member, (Director 1952) he has been active on committees such as the Student Chapters, Chemical Engineering Education (Accrediting, Projects), Testing Techniques, and Equipment Performance Standards. He received his Ph.D. from the University of Pennsylvania.

WHERE are we going in chemical engineering? One main objective in this pursuit is the development of the mind and attitude of a student to enable him to attack process and other chemical engineering problems. This author sees two paths into the future.

The first path is to continue the present mode of our curricula and crystallize the present teaching pattern in unit operations and process patterns. This will tend to the setting up of codes and rigid classifications and is likely to minimize underlying principles which still have new uses and applications. I believe that there is danger that this will lead to a rigid teaching discipline, an outmoded theory will be perpetuated and a rigid attitude created in students. Already this has occurred in some of our science teaching and in other branches of engineering education. The handbook is too often used for the final answer rather than as a starting point to be followed by clear thinking.

The second path to the future envisages a recasting of our present notions of reaction rates, kinetics, unit operations, and processes by use of broader basic fields, such as fluid mechanics, mass transfer, and energy transfer.

Of these two, the second is preferable. We need new techniques to handle the increasing amount of available knowledge to apply to any given problem. The present unit operations overlap and are not standing the strain to which they are being subjected. New unit operations are added every few years, and it is found that each new one is based mostly upon fluid mechanism (in fluidizing), mass transfer (extraction) or other broad scientific fields. Hence, with this type of growth, it seems we should remodel our techniques of teaching and classification of basic principles.

To predict the future, this author visualizes a reorientation in five to ten years of unit operations and process work in accordance with the following basic pattern:

1. Mechanics of fluid and energy transfer with extension to all rate mechanisms.
2. Material and energy balances and rate coefficients.
3. Thermodynamics.
4. Reaction kinetics and catalysts.
5. Equipment for industrial operations.
6. Process design.
7. Research.

A reader might say that all those subjects are covered at the present time. That is true, but we are not emphasizing the broadest bases of the scientific concepts. This line-up has emphasized the mechanics and physics of the processes. We must not lose sight of the chemistry in industrial processing, but this, it seems to this author, can be given emphasis by choice of problem illustrations incident to the teaching of these mechanistic principles.

The next step in the development of chemical engineering education might be thought of as an extension of mechanics, reaction kinetics, and thermodynamics, to process integration. For example, in recent years there has been a marked extension of our knowledge of fluid mechanics. Fluid motion and turbulence are related to mass and heat transfer and are of prime importance in all fluid-processing operations. In fact, in the field of mixing, it is only in recent years that the principles of fluid mechanics are available and are now slowly being used. These are the same basic elements applicable to fluidizing, extraction, and other operations. Thus, ideas are changing as to how to teach mass transfer and heat transfer and other processing operations. Some of our best developments coincided with the changes in techniques and in attitudes toward our profession, so, fresh approaches to the teaching patterns are welcome. We are tending to make our programs too inflexible; rather should things be kept fluid. There are signs that we are settling down in our techniques just as some of the other branches of engineering have done. Why, for instance, should we be teaching chemical engineering thermodynamics when thermodynamics has been taught in engineering schools for many years. Perhaps it is because of the feeling that there has been a crystallization in the techniques by which thermodynamics has been taught by others and we teachers wish to give broader concepts in our own courses. We in turn must guard against such crystallization.

Again the question looms—Whither

Chemical Engineering Science? It depends upon our attitude toward it as professional and scientific persons. If we treat it as either an art or a science, constantly seeking for better integration of all facts necessary to solve new situations, it will expand and develop in ways that we cannot now foresee. We must be sure that it will change, and that is how we shall make progress.

ENGINEERING — ART AND SCIENCE

THOMAS K. SHERWOOD

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THOMAS K. SHERWOOD was a professor at M.I.T. from 1930 until he was made dean of engineering in 1946. He has been a consulting engineer for twenty-seven years. Professor Sherwood acted as technical aide, consultant, division member of the N.D.R.C. from 1940-46. A recipient of the U. S. Medal for Merit in 1948 and the William H. Walker Award (1941), Dr. Sherwood, Director of the Institute (1947), has contributed his advice to the Chemical Engineering Education Projects Committee and the Papers Committee. He received his ScD. from M.I.T. in 1929. Last month he relinquished the deanship to devote his full time to teaching and research.

THIS author strongly disagrees with the suggestion often made that chemical engineering should avoid the idea of being an art. It was Einstein, I believe, who said that scientists are those people who solve the problems which they can solve, and engineers are the people who solve the problems which have to be solved. The decisions which make progress possible in engineering—construction, design, management, and so on—usually are based on inadequate data and made on the basis of experience and judgment. Such decisions represent the highest form of expression of engineering. It would be dull business, indeed, if we knew enough about all the atoms to calculate everything that could happen. That's my criticism of the objection to engineering as an art.

My complaint about the comments of others is that their framework for the systematizing of chemical engineering knowledge is based largely on what exists—on the problems that we see in industry in relation to present-day processes. There seems to be a great moral for us in the history of mechanical engineering, because if the mechanical engineers had been intellectually a little more alert, they would have taken up physical chemistry and there might never have been any chemical engineering.

To go back then to the question of systematizing knowledge and write about it with a little different approach—systematizing is, of course, extremely helpful. If we can get a framework to hang our ideas on we can handle more ideas at one time. And this is good. That's what the unit operations concept did for chemical engineers. But as has been suggested, our frontiers have expanded, the world has become more complicated, or perhaps we have accepted more challenges, and it does seem as though that framework is becoming obsolescent.

Now there is another approach—in fact there are many. The second one is an old one. It appeared in the preface to Lewis and Radasch's "Stoichiometry," in 1926. Chemical engineering concepts were described as falling in three areas as follows:

1. Basic principles, such as energy balances, material balances, the law of combining weights, etc.
2. The whole field of equilibria—physical equilibria, chemical equilibria, and the second law of thermodynamics.
3. Rate equations and rate concepts.

It may be helpful to consider still a third system. That is the division into three

Here are six of the seven—Messrs. Brown, Sherwood, Elgin, Hachmuth, Pigford, and Rushton all visualizing the part chemical engineering science will play in the future.

areas, the first of which is basic science, primarily physics and chemistry; the second, techniques of application, and third, the application. And by techniques of application is meant design tools—mathematics, graphical methods, design procedures, etc., including the complicated methods for calculating the design of stills for multicomponent distillations. These are techniques of application and the applications themselves are, of course, the current industrial processes.

If we stick to the second and third, namely, techniques of application, and applications—this has generally been done in this discussion—we rule out the flexibility which has really been the tradition of chemical engineering. The great hazard is that we may restrict our interest in basic science to things which are relevant to present applications. As pointed out, that is what the mechanical engineers did, and we stole half of our business from them. The continuing new developments push back the frontiers of chemical engineering not because of better and bigger acid plants, but because of industrial application of pieces of science not previously exploited. There are many examples of this. The whole field of vacuum technology had to by-pass right around the standard chemical engineering fluid mechanics—courses and books—and go back to fundamental principles, because under high vacuum there is slip at the wall. This point was not mentioned in the standard chemical engineering texts. Industrial applications of chromotography, ionophoresis, high-voltage sterilization, or spectroscopy require understanding of basic science in areas previously not thought relevant to chemical engineering. Another example that appeals to this author is in the field of refrigeration. You won't find in refrigeration books any statement to the effect that if you run a thermocouple backward, by running some current through it, one end gets cold. That is the kind of thing covered only in our basic science. Yet the reverse thermocouple may be an example of a piece of basic science which can be exploited to broaden the full industrial picture and make for new things.

The chemical engineer has prospered because he has been versatile, intellectually fast, and his success is due to the traditional broad scientific base of the profession rather than the accumulated empirical engineering know-how. As the profession matures, let us guard jealously our traditional fundamental approach to new technological problems, and not follow the older branches of engineering down the dead-end road of empiricism.

TRAINING IN FUNDAMENTALS

R. G. FOLSOM

University of California, Berkeley, California

R. G. FOLSOM has been actively engaged in research and consulting work associated with rockets and jet propulsion problems. Under his direction, special equipment has been developed and extensive research investigations undertaken in rarified gas dynamics. He has been instrumental in establishing the Process Engineering Curriculum at Berkeley. Dr. Folsom, chairman, division of mechanical engineering, University of California, Berkeley, since 1949, is the author of more than fifty papers on various aspects of Fluid Mechanics. Early in his career he served as engineer, City of Pasadena, working on cement calorimeter tests. In 1933 he became associated with University of California subsequently accepting the assignment of professor of mechanical engineering.

I AM a member of that apparently "late lamented" engineering organization—I mean the mechanical engineers which was so inflexible that it missed an opportunity and passed the ball to the chemical engineers. The curriculum in mechanical engineering at Berkeley has been influenced greatly by Prof. L. M. K. Boelter, now dean of engineering at Los Angeles. His philosophy, if I interpret it correctly, is that, at least for the first four years, there is so much basic information, fundamental information, if you please, that it is not practical to draw a distinction between the various engineering disciplines. As a result, the engineering sciences that are necessary to all fields of engineering, are the same—they should be taught in the same classes without any differentiation between a mechanical, civil, electrical, chemical, or otherwise. The result is a unified curriculum in engineering.

One other observation—it seems to me that at the time the A.I.Ch.E. was formed, the understanding of heat transfer, fluid mechanics, the basic principles of dynamic similarity and mass transfer, were not understood, or were improperly understood, by the engineering fraternity. In order to solve these problems effectively, the chemical engineers evolved the procedure that is now known as unit operations. A magnificent job has undoubtedly been done in systematizing the available information on procedures in this way. However, as a member of the mechanical engineers group, who has passed up the "opportunity," we now think that in some respects we are grabbing the ball again. Instead of specializing on the unit operations, we are saying that there is enough fundamental information in the fields of fluid mechanics, heat transfer, mass transfer, mechanic vibrations and otherwise, that in order to train men for what is going to happen in the next forty years in industry, we are no longer considering as many details of machine design, steam heat power, and other well-known subjects in mechanical engineering; but rather are we providing training in the fundamentals basic to a large number of unit operations. When one of our engineers in the future, has to deal with mixing problems, he will have a firm basis in fundamental fluid mechanics so that he understands dynamical similarity, including the limitations of that approach and what distortion factors may be necessary in scaling up from a small, or pilot plant, to a prototype.

Editor's Note: The articles printed on "Whither Chemical Engineering Science?" were adapted from a symposium of the same name given at the A.I.Ch.E. meeting in Atlantic City. George Granger Brown was moderator. The statement by R. G. Folsom represents a revised edition of the comments made from the floor.

PRESERVING WHAT YOU HAVE

From the Corrosion Engineer's Viewpoint

E. A. TICE

International Nickel Company, Inc., New York

WITH materials of construction for chemical-processing equipment under critical demand, today, the importance of extending the life of existing equipment cannot be overemphasized. Many operating factors affect the corrosion resistance of metals and alloys, and the manipulation of these factors to suit the material being used may play an important part in extending the useful life of the equipment.

The scope of this presentation discusses how the adjustment of three of these factors can alter the corrosion resistance of some materials. Factors to be covered are:

1. Aeration, or presence of oxidizing agents.
2. Velocity of media flow, or agitation effects.
3. Temperature.

These factors may operate independent of one another or may be interrelated. They do not affect all metals and alloys in the same way. To know how to regulate these factors it is necessary to understand the response of a specific material in a particular corrosive medium. Assuming that such knowledge is available or can be predicted with a fair degree of accuracy, the potentialities of operating equipment to yield optimum conditions for best corrosion resistance can be reviewed.

Aeration or Presence of Oxidizing Agent. Since corrosion is an electrochemical phenomenon, the action which occurs can be briefed as follows: In an acidic medium, for example, at the anodic area the metal goes into solution as an ion, with a positive charge, while electrons flow through the metal to the cathodic area. At the cathode, hydrogen ions accept the electrons to form hydrogen atoms. These may unite to form hydrogen gas and leave the surface, or may react with oxygen to form water, or hydroxyl ion or may remain on the cathodic surface as a layer of hydrogen. When this latter action occurs, polarization of the cathodic area results which in turn slows down the corrosion at the anodic area.

Consequently, if there is a supply of oxygen or an oxidizing agent present, the removal of hydrogen at the cathode is promoted which tends to cause the corrosion reaction to continue.

This effect of aeration on the corrosion of an alloy can be illustrated by the data for Monel in sulfuric acid, (Fig. 1). Note the higher rate for air-saturated conditions, which prevails up to 96% concentration. As the concentration is increased above 70%, the acid becomes oxidizing in nature and the corrosion rate increases even in the absence of oxygen. Many metals and alloys respond to aeration or oxidizing conditions in this manner.

Aeration may have a diametrically opposite effect on those alloys which depend upon an oxide film on the surface for their corrosion resistance. In such cases the presence of oxygen or an oxidizing agent tends to maintain this film, which might otherwise be destroyed, and can be beneficial in maintaining good corrosion resistance. This effect can be illustrated by the data for stainless steel in sulfuric acid (Fig. 2). In the absence of the oxidizing agent, copper sulfate, a high corrosion rate occurs, but by adding approximately 20 g./l. of copper sulfate, the corrosion rate is materially reduced.

These two examples serve to illustrate effects of aeration or presence of oxidizing agents in a corrosive medium on the behavior of commonly used alloys in chemical-processing equipment. The next consideration is what manipulations of operating practice are available to obtain the best conditions for an exist-

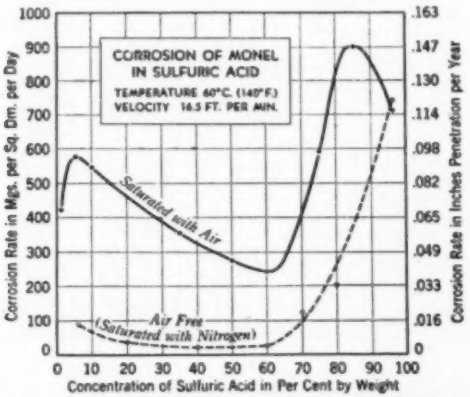

CORROSION OF MONEL IN SULFURIC ACID
TEMPERATURE 60°C. (140°F.)
VELOCITY 16.5 FT. PER MIN.
Saturated with Air
Air Free (Saturated with Nitrogen)
Corrosion Rate in Mgs. per Sq. Dm. per Day
Corrosion Rate in Inches Penetration per Year
Concentration of Sulfuric Acid in Per Cent by Weight
0 10 20 30 40 50 60 70 80 90 100
0 100 200 300 400 500 600 700 800 900 1000
0 .016 .033 .049 .065 .082 .098 .114 .130 .147 .163

Fig. 1. Corrosion of Monel in sulfuric acid, at temperature of 60° C. (140° F.) and velocity of 16.5 ft./min.

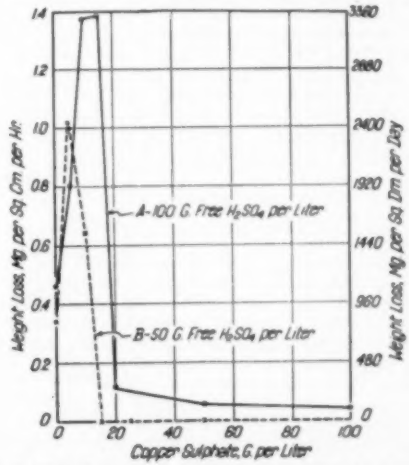

A-100 G. Free H_2SO_4 per Liter
B-50 G. Free H_2SO_4 per Liter
Weight Loss, Mg per Sq Cm per Hr.
Weight Loss, Mg per Sq Dm per Day
Copper Sulphate, G. per Liter
0 20 40 60 80 100
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
0 480 960 1440 1920 2400 2880 3360

Fig. 2. Effect of copper sulphate on corrosion of 18% chromium—8% nickel steel in sulfuric acid at 15 to 20° C. (Monypenny).

ing piece of equipment, such as a mixing tank equipped with an agitator.

In the first case an assumption is made that the equipment is constructed of an alloy which is adversely affected by aeration, as the Monel was in sulfuric acid. How can one keep oxygen or oxidizing agents to a minimum? The answers are:

1. In selecting reactants, choose those which are nonoxidizing, if at all possible. For example, if the medium must be adjusted to the acid side, use of sulfuric acid might be a better choice than nitric acid, since the latter produces oxidizing conditions.
2. Equip the unit with a cover, to reduce the amount of oxygen from the air which can contact the medium. This is particularly effective if considerable agitation is employed.
3. For agitation, employ mechanical methods rather than air agitation, which sometimes may be chosen because of its availability.
4. Since oxygen solubility is a function of temperature, select a temperature range which leads to low-oxygen solubility.
5. Remove oxygen from the water or other media employed in the equipment. This practice is commonly employed in steam-generating plants where the feed water is passed through deaerators prior to entry to the boilers.

In the second case, one can assume that the equipment is constructed of an alloy, such as a stainless steel, which depends upon an oxide film for its corrosion resistance. Listed below are some of the adjustments in operation which could be made.

1. In selecting reactants, choose those which are oxidizing in nature if at all possible.
2. Omit the use of a cover, or arrange for circulation of air so that it can contact the medium. This is particularly effective if rapid agitation is employed.
3. Employ air agitation if compressed air is available, or consider addition of air as an assist to mechanical agitation.
4. Omit crevices in the construction of the unit where an oxygen concentration cell could develop. This can be accomplished sometimes by employing fillet welds at joints which might otherwise exist. A serious problem of this kind was solved in the case of tube ends protruding through a tube sheet in a heat exchanger. Welding of a fillet around each tube to preclude the presence of the crevice, eliminated the difficulty. Another problem of crevice corrosion of tubes at baffle sheets was materially reduced by enlarging the holes in the baffles to permit free circulation between the tube and baffle hole.
5. If a precipitated product or sludge results in the process, which can accumulate on the metal surface, periodic removal of this product is advisable to prevent crevice corrosion under the deposit.
6. If some selection of operation temperature is possible, choose a range for maximum oxygen solubility.

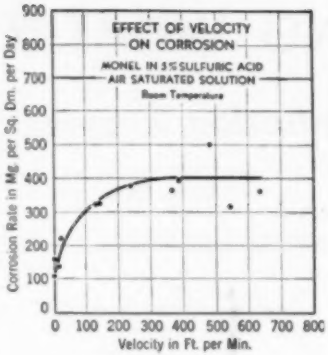


Fig. 3.

Velocity Effects

An increase in the velocity of flow of corrosive media past a metal surface tends to accelerate corrosion. This effect is due to the higher rate at which the media are brought to the metal surface, and the corrosion products, which might otherwise accumulate and slow down the reaction, are removed. If the velocity of flow is sufficiently high, it may even prevent the formation of a corrosion product on the surface.

On the other hand, an increase in velocity may reduce or prevent corrosion of those alloys which depend upon the presence of oxygen or an oxidizing agent for their corrosion resistance, by maintaining an adequate supply of the necessary constituent at the surface of the alloy. Increasing velocity may prevent also the deposition of foreign materials on the surface which could lead to concentration cell corrosion. Thus, velocity may be beneficial as a result of its effect in changing another controlling factor.

The first effect can be illustrated by the performance of Monel in dilute sulfuric acid (Fig. 3). It will be noted that the corrosion rate increases steadily with an increase in velocity up to about 250 ft./min., and levels off with some degree of irregularity above 300 ft./min. Presumably, the rate of diffusion of the corrosive through the corrosion product film, and the sloughing off of the film, have reached a state of equilibrium at about 250 ft./min., and further increases in velocity do not disturb this equilibrium.

Some materials have the characteristic of being able to maintain a protective corrosion product film up to some critical velocity, but beyond which the film is removed and corrosion proceeds at a high rate. This effect is illustrated by the data in Figure 4 which were

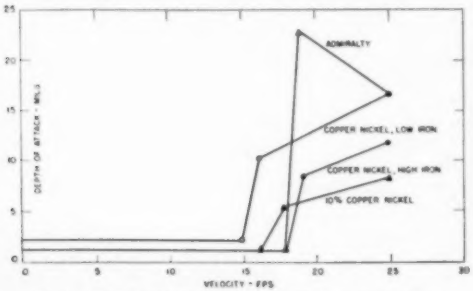


Fig. 4. Effect of velocity on depth of attack in sea water at Kure Beach, N. C. for 60 days.

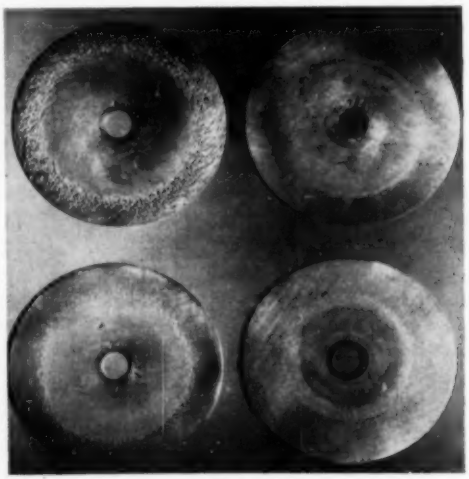
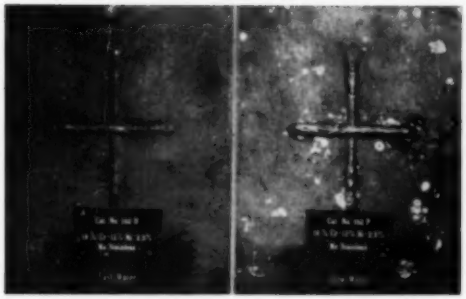


Fig. 5.
Upper left: admiralty brass.
Upper right: 90-10 cupro nickel, 9.7% Fe.
Lower left: 70-30 cupro nickel, 0.4% Fe.
Lower right: 70-30 cupro nickel, 0.05% Fe.



▲ Fig. 6. Effect of velocity of flow of sea water on corrosion of Type 316 stainless steel.

obtained from thickness measurements of the discs, shown in Figure 5, which were rotated in sea water (*2*).

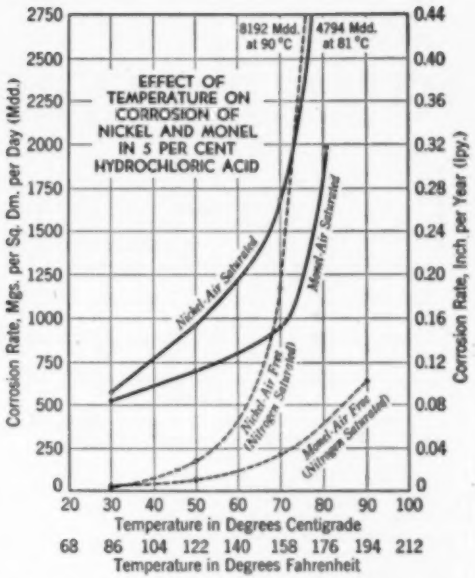
The second effect of velocity—maintaining corrosion resistance by a supply of oxygen at the surface of the alloy, and preventing deposition of foreign products—can be illustrated by the performance of stainless steel in sea water (Fig. 6). Here it will be noted that under quiet conditions marine organisms were able to attach themselves to the surface and set the situation for oxygen concentration cell corrosion to proceed, resulting in severe pitting attack. Under conditions of higher velocity, sufficient oxygen in the sea water was maintained at the surface of the alloy and marine organisms were prevented from depositing, with the result that good corrosion resistance was maintained.

Although the illustrations just mentioned show the manner in which velocity may affect the corrosion process, it must not be assumed that these particular alloys will be affected in a similar manner in all corrosive media. Whether or not the product is adherent will depend upon the nature of the corrosion product formed. Consequently, it is essential that some knowledge of the effect of velocity of the particular medium be available before one can decide how to use velocity to best advantage. If it is assumed that such knowledge is available, operating procedures, employed to obtain optimum corrosion resistance, can be considered.

First, this paper considers alloy equipment which is known to be adversely affected by increase in velocity. The following steps would be helpful.

1. Prevent impingement of the corrosive on the walls of the equipment, or install expendable baffle plates to absorb this impingement attack.
2. If piping deteriorates because of high flow velocities, use of larger diameter pipe, resulting in a lower velocity of flow, may greatly extend the useful life of the pipe material.
3. In heat-exchanger service, selection of a velocity level below that critical for removal of the corrosion product film is most important.
4. Employ as much stream-line flow as possible in the design of piping, to minimize turbulence at changes in direction of flow. For example, attack due to turbulence at tube ends can be reduced often by use of plastic ferrule inserts.
5. Where agitation equipment is involved, use of larger arms or greater agitator surface, operated at slow speeds, is preferable to use of a small agitator operated at high speed.

Fig. 7. ►



Considering equipment which will be benefited by agitation of the medium, or use of high velocity, the following steps would be helpful.

1. In piping, use as small a diameter pipe as is practical, to obtain high rates of flow.
2. Use agitators to keep the medium in motion, particularly if a suspended phase could settle out possibly causing concentration cell action under the deposited phase.
3. Although rate of flow through tubular heat exchangers generally is sufficiently high, sometimes it may be advisable to increase velocity by altering the design, in order to have multiple pass flow at high velocity rather than once-through flow at a low velocity.
4. If reasonably long shutdowns are to be encountered, the equipment should be drained to prevent local attack due to stagnant conditions.

Temperature Effects. Corrosion rates of metals and alloys generally tend to increase with a rise in temperature of the corrosive media. This effect can be illustrated by data in Figure 7 for Monel and nickel in hydrochloric acid. These data show that under air-free conditions, nickel might be usable in this media at temperatures up to about 120° F., but would have too high a corrosion rate at temperatures of 150° F. or higher.

A secondary effect of temperature is its influence on oxygen solubility, which has been discussed previously. Data in Figure 8 for Monel in 5 to 6% sulfuric acid serve to illustrate this effect. In the air-saturated solution the corrosion rate increased rapidly to a peak at 70 to 80° C., and then decreased sharply with a further increase in temperature, as the oxygen solubility decreased sharply. The stainless steel, on the other

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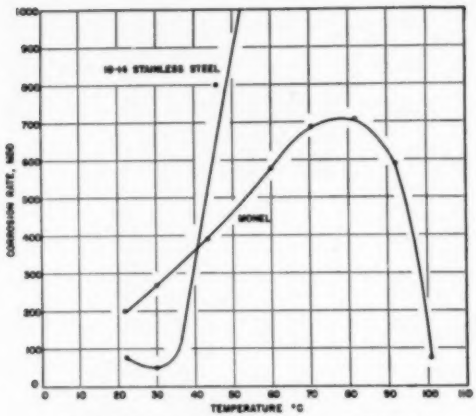

Fig. 8. Corrosion of metals in 5 to 6% sulfuric acid (air-saturated solutions: velocity 15.5 ft./min.)

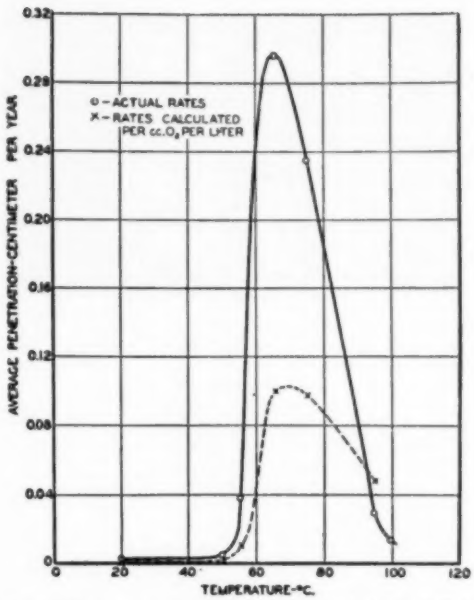

Fig. 9. Effect of temperature on corrosion rate of zinc in distilled water.

hand, which in this medium depends upon the presence of oxygen for its corrosion resistance, suffered a sharp increase in corrosion rate as the temperature was increased, in spite of the oxygen solubility increase.

Temperature may have another effect by increasing the solubility of the corrosion product film which tends to be protective. This effect is shown by the performance of chemical lead in dilute hydrochloric acid. The lead chloride corrosion product film is relatively insoluble in a cold solution, and the corrosion rate is low enough for lead to be usable. As the temperature increases, however, the solubility of lead chloride increases, the film no longer furnishes protection, and the corrosion reaction can proceed rapidly.

Temperature may have still another effect, that of changing the corrosion product film structure from a protective to a nonprotective one. Cox (*1*) observed that such a change takes place in the case of zinc in distilled water. Data in Figure 9 illustrate Cox's observations. Examination of the zinc hydrate film showed that the rapid increase in corrosion coincided with a change in the nature of the film from an adherent gelatinous state to a nonadherent granular state.

Thus, it is apparent that temperature may have a number of effects, some possibly combining to aggravate corrosion, and others, to lessen it. In a great many cases, the operator may have little choice in the matter of selecting an operating temperature range from the standpoint of its effect on corrosion, since the process dictates the temperature to be employed.

The following cases may serve to indicate relatively simple changes which can be made to overcome some adverse effects of temperature.

1. A steam-jacketed kettle was found to be suffering accelerated attack in an area directly opposite the steam inlet. By installing a baffle plate in the jacket in front of the steam inlet, this "hot spot" and the accelerated local attack were eliminated, thus lengthening the useful life of the kettle.
2. A tank equipped with a steam coil located within an inch of the side wall suffered severe attack immediately adjacent to the coil. This was due to both the increased heat and the agitation of the medium resulting from boiling. By relocating the coil about 6 to 8 in. away from the tank wall, this severe attack was greatly reduced.
3. A fume exhaust stack handling a mixture of water vapor and corrosive gases suffered bad attack near the top where the gases became cooled to a temperature below the dew point, causing condensation of an acidic solution. By insulating the stack, the gases were maintained at a temperature above the dew point, thus preventing condensation and the resulting corrosion.
4. A flat-bottom tank was heated by direct fire from the bottom. The tank was supported on a steel bar frame in direct contact with the bottom. After use for some time the inside surface opposite the steel framework showed accelerated attack because of the greater heat intensity in these areas. The trouble was alleviated by altering the support structure so that the tank bottom was entirely free of contact with the steel.
5. In the case of steam coils in an open vessel, accelerated attack on the coils was encountered at the liquid level where violent boiling action occurred. By installing a pipe section of the same alloy but of larger diameter over the inlet section, and attached to the coil several inches below the surface, this hot spot at the liquid level was eliminated and the coil service life was greatly increased.

The cases just cited illustrate how relatively minor changes in the equipment usage were able to overcome the corrosive effects caused by increased temperature, without altering the temperature of the process itself.

When temperature of operation can also be adjusted, careful evaluation of its effect on corrosion of the metals and alloys being used can sometimes lead to selection of optimum temperature for minimum corrosion rate.

In conclusion, the reader is reminded that a number of factors, in addition to the nature of the corrosive, affect the corrosion resistance of processing equipment. Three of these factors have been discussed from the standpoint of their manipulation to create conditions most favorable for long life. As industry is forced to get by with the equipment available, and to use alloys which may not be the most foolproof for a particular application, such manipulation of influencing factors may be of vital importance to the useful life of the equipment.

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CORROSION IN CO_2-H_2S-AMINE SYSTEM

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The increased utilization of natural gas from sour gas areas has multiplied the number of plants using amine systems for gas sweetening. In some cases, severe corrosion problems have been encountered in these systems.

In one plant, corrosion of the tubes in the reboiler of the amine regenerator was so rapid that failure of the tube bundles occurred in two to three months. Operating conditions of this one particular system were simulated on a pilot scale. It was found that the metal attack could be reproduced when the amine contained small residual amounts of both carbon dioxide and hydrogen sulfide and the heat medium oil was 500° F. Reduction of the oil temperature to 370° F. practically eliminated the corrosion in the pilot unit. It appeared that, in this particular system, an excessive metal temperature due to the heating medium was the principal factor in the corrosion of the tubes by stripped amine solution.

THE utilization of natural gas from sour gas areas has resulted in the installation of a number of plants which use aqueous amine systems for gas sweetening. The process consists of scrubbing the gas with an aqueous solution of an amine, e.g., monoethanolamine, which removes hydrogen sulfide and carbon dioxide, and then stripping these gases from the amine in a separate stripping column. Amine contactors purifying natural gas are operating at pressures from 30 lbs./sq.in. to 1500 lbs./sq.in. gage. They normally operate at pressures of about 200 lbs./sq.in. The stripper may operate at pressures up to 45 lbs./sq.in. gage and bottom temperatures up to 300° F. for monoethanolamine water solution. Although heat is usually applied to the reboiler by condensing steam, under certain investment and utility requirements it may be advantageous to use a circulating heat medium oil.

Corrosion problems have been encountered by other workers (*1-3*) in aqueous amine and glycol amine systems. The present study was made when an aqueous amine reboiler which used oil as a heat-transfer medium failed after two months' operation. The gas which was being treated contained about 1% H_2S and 6% CO_2.

A pilot plant reboiler unit was constructed and operated at conditions approximating the commercial installation to study the effects of operating variables on corrosion. It was not known whether CO_2 or H_2S, or both were the cause of the corrosion in the commercial unit. It was thought that the corrosion could be reduced by lowering the heat medium temperature to lower the film temperature on the amine side of the tubes. A series of runs was planned to determine the effect of CO_2, and CO_2 and H_2S in the amine solution at heating oil temperatures of 500° F. If excessive corrosion occurred in the presence of CO_2 and H_2S with heating oil temperatures of 500° F., it was planned to repeat the test with a heating medium oil temperature of 370° F. This lower temperature was chosen because calculations showed that the commercial installation could operate under these conditions with only minor piping changes.

Experimental Equipment and Procedure. A pilot-scale reboiler and auxiliary equipment were constructed to duplicate the essential features of the commercial unit. This consisted of a shell-and-tube-type reboiler utilizing on the shell side a 30-vol. % solution of MEA containing small quantities of CO_2 and H_2S. A flow diagram and details of the reboiler construction are presented in Figures 1 and 2.

The reboiler tube bundle consisted of three 16 B.W.G. plain carbon-steel tubes, ¾-in. O.D. and 30 in. in length. One end of each reboiler tube was welded shut while the other was rolled into the carbon-steel tube sheet which was 3 in. in thickness. A bayonet tube, 7/16-in. O.D., was inserted into each reboiler tube, providing an annular space for the circulation of the heat medium oil. New tubes were installed before each run. The main MEA solution was circulated through a preheater and into the reboiler. The temperature of the MEA entering the reboiler was thus held a few degrees below the reboiler temperature. A metered side stream of MEA was cooled and passed through a unit in which CO_2 and/or H_2S were absorbed. The concentration of acid gas in the MEA returning to the reboiler was controlled by adjusting the rate of MEA flow to the absorber, and the ratio of H_2S to CO_2 in the make-up gas to the absorber.

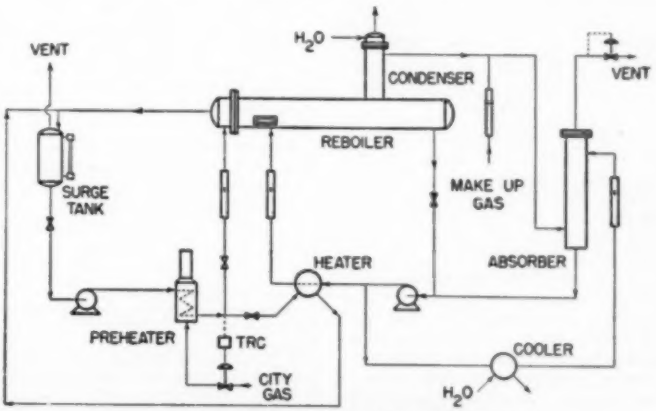

Fig. 1. Flow sheet—MEA corrosion experiments.

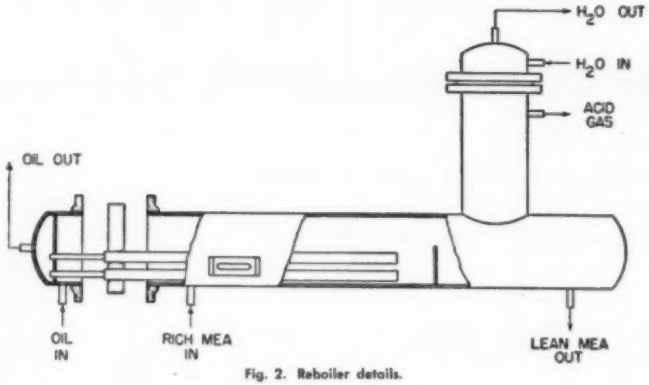

Fig. 2. Reboiler details.

The unit was operated for approximately two weeks at each of the conditions summarized in Table A.

All tubes were rolled into the tube sheet in a similar manner in Runs 1, 2, and 3. In Run 4, tube 1 was rolled to a depth of 2 in., tube 2 was rolled to a depth of 1 in. and fitted with an insert, while tube 3 was rolled for the full 3 in. of the tube sheet.

The reboiler tube diameters were carefully measured before and after the 14-day runs and examined for evidence of corrosion. During the run daily samples of MEA solution entering the reboiler were analyzed for acid gas and MEA concentration. In the last two runs the MEA solution leaving the reboiler and the acid gas to the absorber were sampled and analyzed for H_2S content.

It was found that accurate determination of the CO_2 content of MEA could not be obtained by acidifying the solution with either 50 or 85% phosphoric acid even with agitation and heating. A procedure was developed in which the CO_2 was precipitated from solution as barium carbonate. This method gave results on test solutions within 1% of the known value. The concentration of MEA was determined by acid titration.

Results

After Run 1 the tubes were found to be coated with a hard black scale and were slightly etched beneath the scale. A white salt-like deposit was found on the tube sheet just above the MEA level, probably because city water was used in making up the solution. In the remaining runs fresh solution was made up with steam condensate.

At the end of Run 2 the tubes were found to be coated with a viscous dark-brown liquid which was insoluble in acetone but dissolved readily in water. Tube surfaces were slightly etched a few inches from the tube sheet.

During Run 3 the MEA solution became densely loaded with a black flocculent suspension. Samples collected during the run were filtered, and the black residue was washed and treated with sulfuric acid. Hydrogen sulfide was liberated, indicating the presence of a sulfide. At the end of the run the tubes were smooth except for an area approximately 10 in. from the cold end and at the tube sheet. In these areas the tubes were pitted. The entire area of all tubes was found to be coated with a hard black material. Micrometer measurements indicated a reduction in outside tube diameter at all points. At the junction of the tubes and tube sheet all tubes were corroded in a ring approximately ⅛ in. wide. Penetration was measured to be from .016 to .032 in., or one quarter to one half of the tube thickness.

After Run 4 the tubes were found to be coated with a viscous dark-brown liquid which was insoluble in acetone but dissolved readily in water. This was similar to Run 2. Since outside surfaces of the tubes within the tube sheet were rough, a new tube was rolled in and immediately removed. The same rough surface was present and indicated that the tube sheet had been corroded enough in the previous run to cause the uneven surface.

Tube diameter histories are recorded in Table 1. Evidence of significant area corrosion was found only in Run 3 where the reduction in tube diameter averaged 0.0026 in. Evidence of severe pitting, as shown in the photographs of Figure 3, was also found only in Run 3, which was conducted at a heating-oil temperature of 500° F. in the presence of CO_2 and H_2S.

The concentration of MEA throughout each run is shown in Table 2. A decrease in concentration was noted in Run 1 and, although precautions to maintain a closed system were taken in the other three runs, a similar decrease was observed in Run 2 and in parts of Run 3. In Run 4 at a heating-oil temperature of 370° F. the concentration was relatively constant.

Discussion of Results

Corrosion. The decrease in outside tube diameter and the deep pitting of the tubes in Run 3 clearly show that corrosion was most severe in this run. The corrosion at the junction of the tube and tube sheet had penetrated approximately one half of the tube wall. The expected life of the tube under the conditions of hot oil at 500° F. and in the presence of H_2S and CO_2 would be about six weeks.

The only evidence of corrosion observed during the other runs was a slight etching of the tube surface. The two conditions (of 500° F. heating oil within the tube boiling MEA containing N_2 (Run 1) and CO_2 (Run 2)) did not result in appreciable corrosion as indicated by visual observation. The last condition of 370° F. heating oil within the tube and both H_2S and CO_2 in the MEA gave similar results, which are assumed to represent industrially safe rates of corrosion. It is concluded that by reducing the heat-medium temperature from 500° F. to 370° F., corrosion in the pilot plant unit was eliminated. Since stripping out all the H_2S before the solution reached the reboiler might prove to be uneconomical, a reduction in the heat-medium temperature would be the most practical corrective measure in this situation if adequate surface were available.

MEA Decomposition. The history of MEA concentration (Table 2)

TABLE A.

Run number	1	2	3	4
Oil temp. to reboiler, ° F.	500	500	497	372
Oil temp. from reboiler, ° F.	435	447	448	360
Oil flow, lb./hr.	1,480	1,480	1,480	3,100
Gas to absorber	N_2	CO_2	CO_2+H_2S	CO_2+H_2S
MEA circulation rate, gal./min.	0.11	0.11	0.11	0.11
Reboiler pressure, lbs./sq.in. gage	30	30	30	30
Acid gas concentration				
CO_2 in MEA, v/v	0	———	3 to 4	———
H_2S in MEA, gr./gal.	0	0	———	2 to 5 ———

TABLE 1.—TUBE DIAMETER MEASUREMENTS, INCHES

Tube No.	Inches from Tube Sheet	Run No. 1		Run No. 2		Run No. 3		Run No. 4	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
1	6	.7550	.7549	.7528	.7532	.7526	.7505	.7502	.7502
	12	.7551	.7548	.7538	.7530	.7526	.7505	.7502	.7503
	18	.7551	.7548	.7538	.7535	.7529	.7491	.7504	.7503
	24	.7562	.7551	.7532	.7530	.7530	.7499	.7503	.7504
2	6	.7550	.7551	.7530	.7532	.7535	.7511	.7502	.7504
	12	.7550	.7550	.7530	.7530	.7535	.7494	.7502	.7502
	18	.7555	.7550	.7530	.7529	.7531	.7490	.7502	.7503
	24	.7562	.7550	.7533	.7531	.7534	.7504	.7502	.7503
3	6	.7551	.7550	.7535	.7535	.7532	.7515	.7504	.7502
	12	.7552	.7551	.7537	.7535	.7533	.7511	.7502	.7503
	18	.7557	.7551	.7535	.7535	.7532	.7520	.7503	.7503
	24	.7554	.7556	.7536	.7538	.7533	.7508	.7502	.7503
Average reduction in tube diameter, inches × 10^4		3		1		26		0	

shows a rapid loss of MEA in Run 2. A similar trend is shown also for parts of Run 3, but in this run the absorber vent temperature was higher than in the previous run. This would allow water to be lost from the system, which would increase the concentration of MEA. Following Run 3, four baffles were installed in the condenser, which increased its efficiency and reduced the operating temperature of the absorber. In Run 4 the concentration remained relatively constant. Although the data are not conclusive, it is indicated that substantial decomposition of MEA occurred when at a heat-medium temperature of 500° F.

Literature Cited

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2. Riesenfeld, F. C., and Blohm, C. L., *Petroleum Refiner*, **29**, p. 141 (April 1950).
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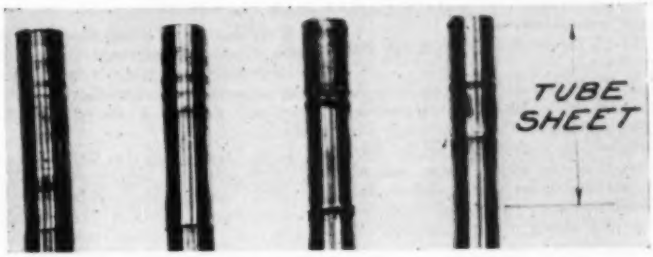
Discussion

B. B. Kuist (Fluor Corp., Los Angeles, Calif.): Mr. Davis has certainly put his finger on two important determining factors in corrosion—temperature and the presence of acid gases. He also briefly mentioned the glycol amine process which is outside the scope of his paper. You probably know that the Fluor Corp. has the glycol amine process. The addition of glycol changes the situation in the reboiler, and probably the simplest way to describe the change is to say that the glycol raises the boiling point of the solution. In other words the temperature is raised for any given operating pressure. However, the stripping is much improved and the acid gases present in the reboiler are therefore decreased. The net effect is, as far as we can observe, less corrosion in the reboiler than generally encountered with aqueous solutions.



Run 1. Run 2. Run 3. Run 4.

G. R. Davis: I believe that could be seen at least to some degree on our Run 2 where we had carbon dioxide but no hydrogen sulfide, and we didn't get corrosion even with the hot oil.

Anonymous: Would you please comment concerning the likelihood that cold working of the tubes is responsible for the observed corrosion?

G. R. Davis: I presume the question refers to stresses resulting from expansion of the tubes when rolled into the tube sheet. The tube sheet in question is three inches thick. The tubes, however, were rolled into the tube sheet for two inches only. In this manner no part of the expanded (cold worked) portion of the tube was within one inch of the hot solution so that stress corrosion of either the commercial or the pilot plant reboiler is unlikely. In Run 4 with heat medium oil at 370° one of the tubes was expanded for the full three inches into the tube sheet so that the stressed portion of the tube actually was in contact with the hot solution. Corrosion was no worse on this tube than on the companion tubes expanded in the conventional manner.

TABLE 2.—MEA CONCENTRATION, VOLUME PER CENT

Days on Stream	Run 2	Run 3	Run 4
Start	30.0	30.0	29.9
5	29.7	26.7	30.1
10	26.0	29.3	31.2
14	24.3	31.2	29.8

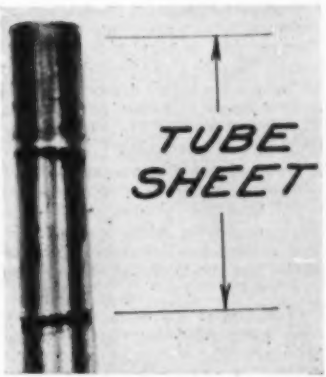


Fig. 3. Photograph of pittings.

Alan S. Foust (University of Michigan, Ann Arbor, Mich.): Your data on the rapidly corroding run indicated significant general corrosion. I got the impression that the ring of corrosion at the tube sheet did not surprise you. Was the bundle in the commercial unit found to have corroded uniformly or predominantly in the rings at the tube sheet?

G. R. Davis: With the plain carbon steel tubes the corrosion was predominantly at the tube sheet. However, it was a four-pass unit and there was failure at the tube sheet pretty much only in the first pass—that is where the hottest oil entered the tubes. When stainless tubes were used, corrosion was much more general. As far as I know, this ring was not visible at all with the 304 stainless.

C. J. Randolph, Jr. (Girdler Corp., Louisville, Ky.): You made one test where you mixed the H_2S and observed corrosion, and with CO_2 alone, you observed little additional corrosion over the nitrogen. Did you run any tests with H_2S in the same concentration as the plant solution with no CO_2 and did you have any corrosion?

G. R. Davis: No, we did not make such a test.

F. E. Miller (Fluor Corp., Los Angeles, Calif.): In regard to the ring-type corrosion, Fluor has made some rather comprehensive studies on corrosion in glycol-amine plants, and also in aqueous amine plants, and we have found that the ring-type corrosion near the tube sheets is very common. We have observed the same sort of a corrosion under heat-exchanger baffles. I believe the reason we have ascribed to the ring corrosion is that it is caused by the higher temperature there (the higher the temperature, the higher the corrosion rate). Under the baffles one does not find so much flow and consequently the tube wall temperature would be higher. The higher temperature tends to strip out the acid gases (CO_2 and the H_2S) more rapidly. These acidic gases do most of the corroding.

Anonymous: Did you overlook or perhaps just not mention that there might have been erosion occurring in the plant bundles which was not covered in the laboratory work? In other words, iron sulfide erosion or something of that sort?

G. R. Davis: Erosion possibilities were investigated by plant operating personnel. The reboiler in question was designed for amine inlet through a 12-in. nozzle close to the fixed tube sheet end of the bundle. Attack at this point was interpreted as being caused by erosion and corrective measures were undertaken. A baffle plate was installed in the tube sheet end of the reboiler shell to prevent direct impingement of feed solution on the tubes. The next bundle went out in somewhat less time than the first and in the same way. We then concluded that erosion was not the predominant attack mechanism.

R. S. Rhodes (Koppers Bldg., Pittsburgh, Pa.): Was there any evidence of corrosion of the tube sheet at the point where the tube entered the sheet?

G. R. Davis: Yes, there was. After the tubes were removed following Run 3, it could be seen there was some enlargement of the holes in the tube sheet.

R. S. Rhodes: Now, what is the possibility that your ring-type corrosion is actually erosion?

G. R. Davis: That question has been discussed to some extent. However, one additional point might be of interest. In an attempt to minimize erosion possibilities, an amine inlet distribution pipe was installed along the top of the reboiler above the solution so that the amine no longer entered through the normal inlet line. This distributor was ineffective in reducing the corrosion rate in the commercial unit.

R. S. Rhodes: I meant erosion from the standpoint of liquid vaporizing in the annular space between the tube and tube sheet, causing vapor erosion. Have you tried seal welding of the tubes to the tube sheet?

R. S. Davis: No, that has not been tried. Appreciable vaporization in the annulus would lead to partial vapor binding and might result in erosion by cavitation. Calculations indicate that vapor binding is unlikely along the main part of the tube but may very well occur within the annulus.

John J. Dorsey, Jr. (Commercial Solvents Corp., Monroe, La.): Referring to Mr. Davis' observation on chlorides, we at Commercial Solvents, have observed as high as 0.5% of chlorides in our amine system which is employed in removing CO_2 from ammonia synthesis gas. We have further observed severe stress corrosion in the CO_2 absorber of our system. Whether this is the result of the 0.5% chlorides present, we cannot say. However, we are attempting to reduce the chlorides to as low a value as possible. A second point: At high temperature differences between the heating oil and the saturated amine solution a deep-ring type of corrosion occurred in the tube near the tube sheet. At lower temperature differences and higher oil rates slight corrosion occurred. Is the corrosion at high temperature differences the result of the rapid evolution of CO_2 and thus really erosion as well as corrosion?

G. R. Davis: The increased temperature difference undoubtedly increases the general corrosion rate but would not account for the deep ring at the tube sheet. We have never found a chloride content greater than about 400 p.p.m. in the circulating amine. Most of this chloride likely comes from make-up condensate. Incidentally, the question was asked whether we had ever used aluminum tubes. We did. I think the Fluor people will bear me out that aluminum tubes appeared to work fine in glycol-amine systems. In this aqueous amine system, aluminum tubes lasted only one day. I cannot say, however, that this short life is the fault of the aluminum because the aluminum tube was installed in a plain carbon steel tube sheet so that galvanic effects may have been important.

N. H. Walton (Atlantic Refining Co., P. O. Box 8138, Philadelphia, Pa.): Do you make any attempt to remove continuously or at intervals, the suspended iron sulfide that builds up in the solution, in order to prevent erosion of pumps and other equipment?

G. R. Davis: Yes—there are filters handling a slip stream of amine in the commercial units. These filters are installed in all plants and run at all times.

N. H. Walton: What type of filter and filter medium is used?

G. R. Davis: We have used bag-type filters, some precoat types.

F. E. Miller (Fluor Corp., Los Angeles, Calif.): In regard to the use of aluminum heat-exchanger bundles, we found that they work very well in heat exchangers for glycol-amine plants, the borderline case being 40% water. When the water content of the treating solution is 40% or more, the use of aluminum heat-exchanger bundles is questionable, but for solutions containing less than 40% water, particularly from 6 to 15% water, aluminum heat-exchanger bundles do very well. We have had several aluminum heat-exchanger bundles installed in commercial plants for about a year now, and they show very little evidence of corrosion. We have also tried aluminum tubes in reboiler service, but there we have had some trouble with them.

W. O. Cochran (Du Pont Co., Wilmington, Del.): Has the plant reduced its temperature thereby curing the situation?

G. R. Davis: We were somewhat in error when we calculated that the plant could reduce the heat medium oil temperature to 370°. We were able, with minor changes, to reduce the temperature to 440° only. I'll give the history on plain carbon steel tubes as it was affected by this temperature reduction. There were three plain carbon steel bundles installed before the heat medium temperature was reduced. The life of those bundles was eleven weeks, nine weeks and eight weeks. The temperature was then reduced according to these recommendations to 440° F. The next plain carbon steel bundle has been in service for 52 weeks and is still operating satisfactorily.

(Presented at A.I.Ch.E. Kansas City (Mo.) Meeting.)

VOLUMETRIC BEHAVIOR AND THERMODYNAMIC PROPERTIES OF ETHYLENE OXIDE

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The volume of ethylene oxide in the vapor and saturated-liquid regions has been measured in a compressibility bomb from 14.7 to 600 lb./sq.in.abs. over a temperature range of 70 to 310° F. Additional data were taken in the critical region (t_c = 384.4° F., p_c = 1043 lb./sq.in.abs., v_c = 0.051 cu.ft./lb.). Polymerization at temperatures above 220° F. was rapid enough to require measurements as a function of time. At 310° F. the volume decrease was 0.4%/hr. Testing of the apparatus with nitrogen and *n*-butane gave results within 0.2% of the accepted volumes for these substances. The inaccuracy of the ethylene oxide volumetric data is believed to be less than 0.3% below 310° F. and less than 1% above 310° F.

Available spectroscopic information was combined with the volume data to determine enthalpy and entropy values in the two-phase and gaseous regions. Results are shown in graphical and tabular form.

DETERMINATION of the thermodynamic properties of oxygenated organic compounds has received little attention in contrast to the effort expended upon hydrocarbons. The rapid development of the synthetic chemical industry suggests that more work on the former group of materials would be worth while. The purpose of this investigation was to develop an apparatus suitable for measuring the pressure-volume-temperature relations of a number of oxygenated organic compounds and to apply it to a particular member of the group. Ethylene oxide was chosen for the initial study largely because of its present and potential importance in the chemical industry.

The published information on the volumetric behavior of ethylene oxide is limited at this writing to the work of Maass and Boomer (*34*), which included the temperature range 14.8 to 96.4° C. but was limited to pressures of 1 atm. and below. The other pertinent thermodynamic data are as follows: pressure enthalpy relations over a temperature of 120 to 300° F. and over a pressure range of 40 to 555 lb./sq.in.abs. (*38*); entropy at 283.66 and 298.16° K., heat capacity from 15 to 285° K., and heats of fusion and vaporization at the melting and boiling points, respectively (*16*); heats of combustion and formation at 25° C. (*6, 29, 36, 40, 41*); specific heat of the vapor in the ideal gas state at 307.18, 337.04 and 371.23° K. (*30*); vapor-pressure data from 15° K. to the critical temperature, 469.1° K. (*11, 16, 22, 34, 38, 39*); compressibility at 25° C. and 380 mm. Hg. (*43*); critical temperature (*22, 34*) and critical pressure (*22*); vibrational-frequency numbers from Raman and infrared spectra (*7, 21, 32, 33*) and molecular constants (*1, 12, 13, 15, 48*); thermodynamic properties for the ideal gas at 1 atm. based on statistical calculations (*19, 20*).

The literature discloses a variety of equipment and techniques for obtaining p-v-T data. The compressibility units vary from capillary tubes (*26, 47*) to large stainless-steel cells of 1- to 2-l. capacity (*2, 10, 27, 28, 35, 44*). Variable- and fixed-volume methods have been used. Pressure is generally measured with dead-weight gages, volume by comparison with an equivalent of mercury, and temperature with platinum resistance thermometers.

Experimental Method

Apparatus. A relatively large-diameter compressibility bomb, rather than a capillary tube, was decided upon in order to increase the precision of the volume measurements.

A cylindrical compressibility cell was machined from a billet of type 304 stainless steel and mounted to form one leg of a mercury-sealed U tube. The other leg of the U tube was an identical steel cylinder serving as a reservoir for the mercury, which could be injected into or withdrawn from the compressibility cylinder by varying the pressure in the reservoir. The latter operation was accomplished with compressed nitrogen and a vent. A schematic illustration of the equipment is shown in Figure 1. A self-sealing Bridgeman-type cover with a Teflon gasket was used on each cylinder as indicated in Figure 2.

The temperature of the system was controlled by immersion of the entire U-tube unit in an oil bath. The bath tank was made from a 35-in. by 23-in. diam. steel drum. Four nichrome-ribbon space heaters were mounted on the outside periphery of the tank and four Variac-controlled finger-type heaters within the tank. A steam coil was also installed in the bath. A Lightning mixer was used to stir the bath. The entire tank was insulated with 4 in. of magnesia followed by a surrounding steel shell. Temperature was maintained by a mercury-in-glass thermostat which controlled a separate heater through a thyratron tube and mechanical relay. Two copper-constantan thermocouples (calibrated at the sodium sulfate, steam, naphthalene, benzophenone, and lead points) were used to measure the bath temperature. The thermoelectric e.m.f.s were read with a Rubicon high precision potentiometer and a multiple-reflector-type galvanometer. It is believed that the temperature of the bath could be measured to 0.05° F., which was approximately the precision of thermostatic control.

The pressure was measured on the nitrogen side of the U-tube and corrected for the head of mercury in the U-tube. An Aschroft gage tester with a range of 25 to 2000 lb./sq.in., was modified according to a technique devised by Kay and co-workers (*25*) to give continuous pressure readings. This method involved attaching a disc with vertical fins to the piston and weight assembly, so that a stream of air directed against the fins caused rotation without mechanical linkage. A small mercury-filled U-tube in the pressure gage line sealed the gage-oil from the nitrogen lines. Two electrically insulated needles, extending into each leg of this device and connected in a circuit with two 1-v. lamps and a battery, indicated the attainment of pressure equilibrium between oil and nitrogen in the U-tube. The vapor pressure of CO_2 at 0° C. (*8*) was employed to determine the gage constant. Commercial dry ice was found of sufficient purity to be used as a source of CO_2 (*45*). All weights were calibrated on the basis of this constant.

The gage was sensitive to 0.025 lb./sq.in. and it is believed that pressures down to 25 lb./sq.in. gage could be measured to 0.05%. Below 25 lb./sq.in. gage, pressures were determined with a mercury-in-glass manometer.

The volume measurement involved a technique, originated by Verschoyle (*47*), centering around the change in resistance of a loop of high-resistance wire vertically suspended in the compressibility cylinder so as to be short-circuited at the mercury surface. Two stainless-steel lead posts passed through the bomb cover into the cylinder, with a Teflon cone used to seal the opening and electrically insulate the posts. The ends of the posts extending into the cylinder were shaped into eyelets to take small modelers' bolts and nuts. To the outer end

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of each post, two glass-insulated copper wires were silver-soldered, one pair leading to an emf. source and the other to the potentiometer. The resistance loop, made of 30% irridium and 70% platinum wire 0.0031 in. diam.) was attached to the posts at the eyelets by means of the modelers' bolts. Two ⅛-in. stainless-steel support rods, mounted on the underside of the cover and turned at the lower ends to take two small compression springs, carried a floating crosspiece to which the resistance loop was attached (Fig. 2).

The compression springs and crosspiece allowed for differences in thermal expansion. In preliminary tests it was found that a small stainless-steel float, drilled to fit snugly around each wire, eliminated the troublesome meniscus effect of the mercury. To calibrate the resistance loop (or probe) to give volume readings, the cylinder was evacuated and completely filled with mercury. With the system at the desired temperature, mercury was withdrawn in steps and the probe resistance measured after each withdrawal, until the cylinder was emptied. The resistance was measured with the Rubicon potentiometer, utilizing a circuit similar in every respect to that for resistance thermometers. The mercury was weighed and its volume at the temperature of the system determined (*24*). The relationship between volume and probe resistance was thus established. An identical probe was built in the cover of the reservoir cylinder in order to determine the relative heights of mercury in the two cylinders. From the reproducibility of the calibration tests, it is believed that the volumes could be measured with an accuracy of 0.1% and mercury levels within 0.5%.

Four weighing bombs of capacity ranging from 6 to 190 g. of liquid ethylene oxide were machined from aluminum. An analytical balance could be used in all weighing except in the case of the largest bomb. A special aluminum valve designed to take removable high-pressure fittings was used on the bomb (Fig. 2).

Procedure. In making a typical run the first step consisted of distilling a sample of ethylene oxide from the storage cylinder into an evacuated and ice-cooled weighing bomb. Ethylene oxide with a maximum impurity of 0.5% by weight was used as received from the Carbide and Carbon Chemical Co. Preliminary tests indicated that purification, beyond the simple distillation when the sample was transferred from storage, would not affect the results significantly.

After weighing, the filled bomb was attached in an inverted position to the upper valve of the compressibility cylinder; the latter had previously been evacuated and filled with mercury. With connecting lines open, mercury was withdrawn from the bottom of the compressibility cylinder and the ethylene oxide transferred by its vapor pressure into the cylinder. By warming the weighing bomb and connecting lines with a mantle, it was possible to evaporate all the liquid in these spaces, so that only vapor was trapped in the 1 in. long and 1/16-in. I.D. line between the valves. With all valves closed the weighing bomb was removed and reweighed. A calculated correction of 0.0003 g. was subtracted for the vapor loss in the connecting line. The line was initially filled with mercury so that air would not be introduced.

With the sample in the compressibility cylinder, the bath was heated to the desired temperature and the nitrogen pressure adjusted to give any volume within the limits of the cylinder. Once equilibrium was established, the pressure, temperature, and volume readings were taken, and if no change occurred within 10 min., these readings were recorded and through calibration curves converted to p-v-T data.

For the vapor-phase measurements the weight of sample ranged from 2 to 20 g. For liquid-phase and vapor-pressure data 370 to 390 g. of sample were used.

Tests of the entire apparatus were made by measuring the volume of nitrogen at 160° F. up to 165 lb./sq.in.abs. and n-butane at 190° F. from 22 lb./sq.in.abs. to the vapor pressure. Results were within 0.2% of those reported for these substances (*44, 42*). The n-butane (99 mole %) was purified by low-temperature distillation before use. The average measured vapor pressure at 190° F. was 11.767 atm. in comparison with 11.757 atm. selected by Prengle, et al (*42*). The variation in vapor pressure was 0.972 atm. as the vapor to liquid ratio was changed fourfold (4).

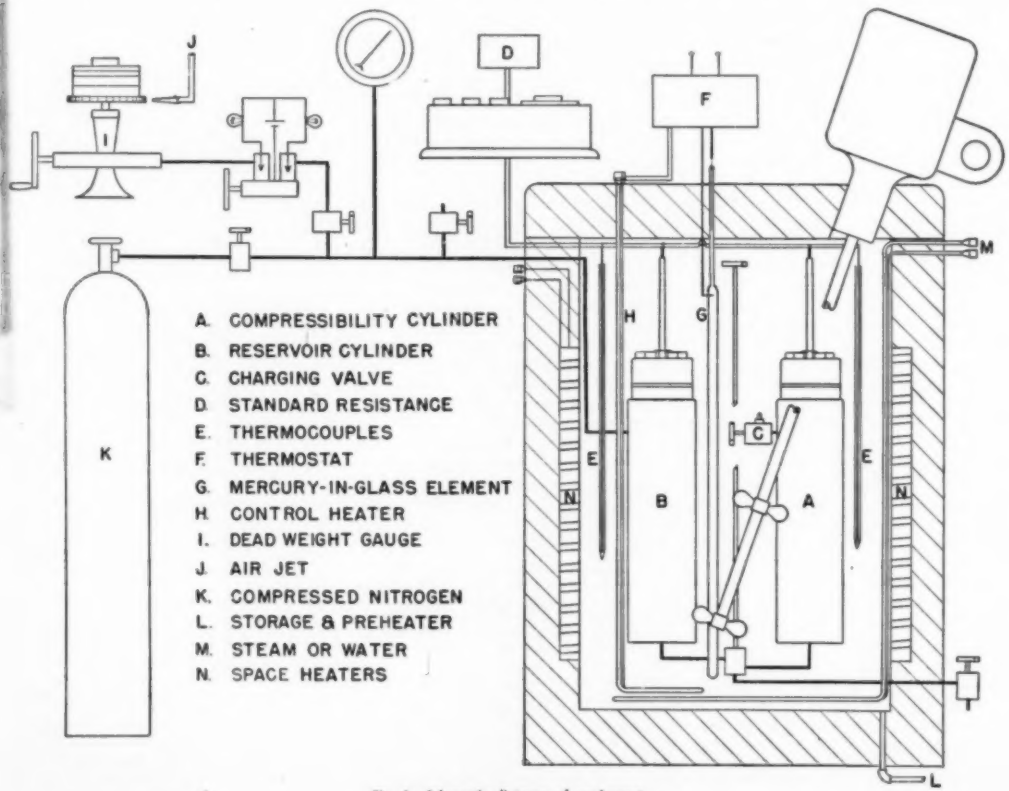

Fig. 1. Schematic diagram of equipment.

Data

The pressure and volume were measured along isotherms beginning at 70° F. and separated by 30° F. intervals. The measurements up to 160° F. proceeded satisfactorily. Results are presented graphically in Figure 3 as residual volumes vs. pressure. At temperatures greater than 160° F. and at low pressures where small samples (2-3 g.) were necessary, the residual volumes were erratically large. Above 220° F. the residual volumes increased with retention time. These effects were traced to polymerization, the oily-to-waxy product being readily washed from the compressibility cylinder with liquid ethylene oxide after each run. The smaller the sample the greater the effect, indicating a surface-catalyzed polymerization. To circumvent this difficulty a maximum sample was used and a time correction applied on the basis of a series of readings taken at different times. By using a fresh sample for each run and preheating the oil so that the first reading could be made within one or two hours after the run was started, data were obtained up to 310° F. An example of the residual volume-time curves is shown in Figure 4.

The initial rate of volume decrease with time at 250° F. was about 0.02%/hr., at 280° F. 0.1%/hr., and at 310° F. 0.4%/hr. The logarithm of the percentage change in volume plotted vs. $1/T$ produced a straight line, corresponding to the equation: $\log k = -11{,}800/T + 13.0$, where k is the fractional decrease in specific volume per hour and T is ° R. From this expression the apparent activation energy for this specific case is 23,500 B.t.u./lb. mole. At 340° F. the rate of decrease of specific volume is predicted to be 1.6%/hr. On this basis it seemed impractical to attempt operating at the higher temperatures. A sample of ethylene oxide taken at the midpoint of a distillation showed the same behavior when tested in the apparatus, indicating that polymerization was not due primarily to the impurities in the oxide.

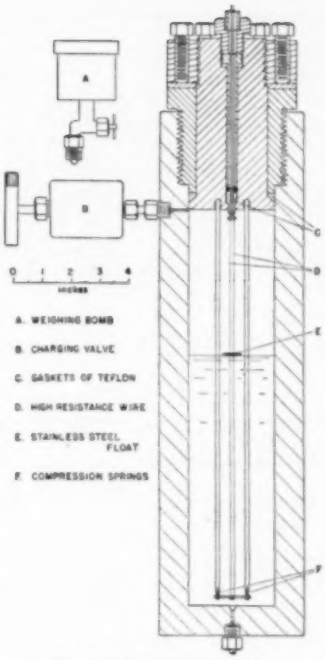

Fig. 2. Compressibility cylinder.

Because of the large permissible samples, vapor pressure and specific volume measurements were made at 340° F., 370° F., and in the critical region without significant polymerization.

Using the concept of rectilinear diameters (*17*) and all the measured saturated volumes, it was possible to estimate the specific volume of the saturated vapor at 340 and 370° F. and the critical volume at 384.4° F. Using this information, together with vapor-phase data extrapolated on the residual volume vs. pressure and temperature charts, the range of results was extended to include all the dome region, and the vapor region to 400° F. and 900 lb./sq.in.abs. All isotherms on the residual volume vs. pressure chart (Fig. 3) were extrapolated to zero pressure assuming the change with pressure to be approximately constant in the lower pressure region. The residual volumes for the saturated vapor were obtained by extrapolating the isotherms to the vapor pressure with approximately constant curvature. This latter step was necessary because premature condensation and perhaps other wall effects would not permit the direct measurement of saturated volumes (*28, 31*).

The smoothed vapor-phase results compare well with the limited data from the literature (*34, 43*); the deviation is less than 0.4%. The vapor-pressure data are in fair agreement with all earlier data (*11, 16, 22, 34, 38, 39*) except that of Mock and Smith (*38*). These authors feel that the temperatures they recorded may have been in error (*37*).

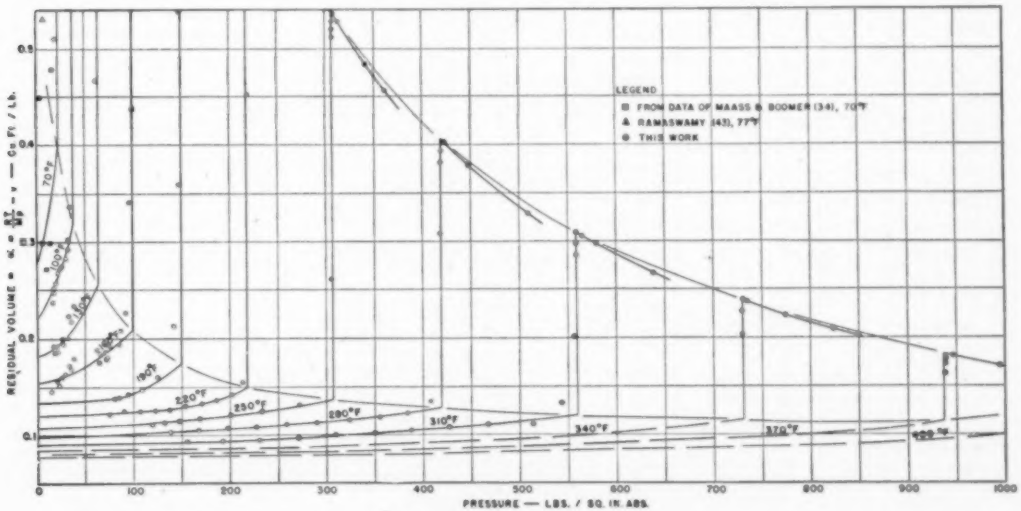

Fig. 3. Pressure-volume-temperature data.

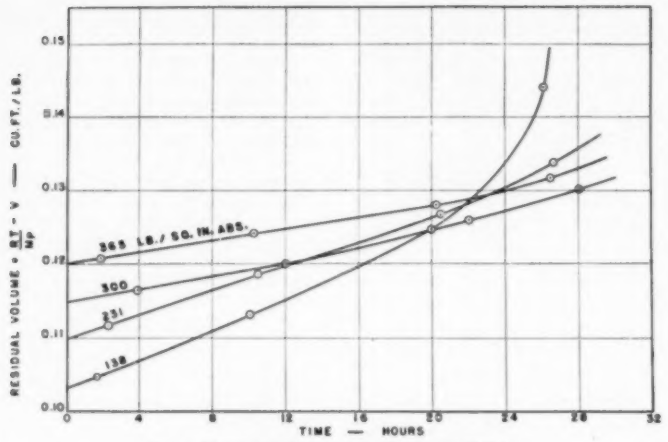

Fig. 4. Change of residual volume with time at 280° F.

A plot of the experimental vapor pressures illustrates the continuity of the different data over the complete temperature range (Fig. 5). The smoothed liquid volumes extrapolate to acceptable agreement with low temperature data (*34, 46*) the deviation appearing to be about 0.5%.

From the over-all point of view it is estimated that the inaccuracy in the vapor phase is less than 0.3% below 310° F. and less than 1.0% above 310° F. The vapor pressures deviate from the following equation by an average of 0.2%,

$$\log p = \frac{-2382.0}{T} + 5.8425 \quad (70 \text{ to } 370^\circ \text{ F.}) \qquad (1)$$

but the inaccuracy of the absolute values is possibly as great as 0.5%. The inaccuracy of the liquid specific volumes is probably less than 0.5% at temperatures below 310° F. and less than 1% from 310° F. to the critical temperature.

The best critical constants are believed to be:

p_c = 1043 lb./sq.in.abs. (*22*)
t_c = 384.4° F. (*22*)
v_c = 0.051 cu.ft./lb. (This work)

The inaccuracy of the critical temperature is estimated to be no greater than 0.5° C. (0.9° F.) (*9*). The vapor-pressure data of the present work extrapolated to 384.4° F. gives a critical pressure of 1049 lb./sq.in.abs., which is in acceptable agreement with the value, just shown, determined by Hess and Tilton (*22*). The critical volume is possibly in error by 3%.

The complete volumetric results are given in Tables 2 and 3. An examination of the data reveals that the generalized compressibility chart (*14*) can be used to predict the behavior of ethylene oxide over the range of the present work with an average deviation of about 2%. The greatest deviation occurs at low temperatures and near saturation.

Calculated Thermodynamic Properties

Although the ideal gas properties are presented in the literature (*19, 20*), these were recalculated here because more recent moments of inertia for the ethylene oxide molecule are available. The statistical calculation of the properties of a substance in the ideal gas state has been thoroughly discussed by Glasstone (*18*) and Hougen and Watson (*23*). The vibrational frequency assignments selected by Kistiakowsky and

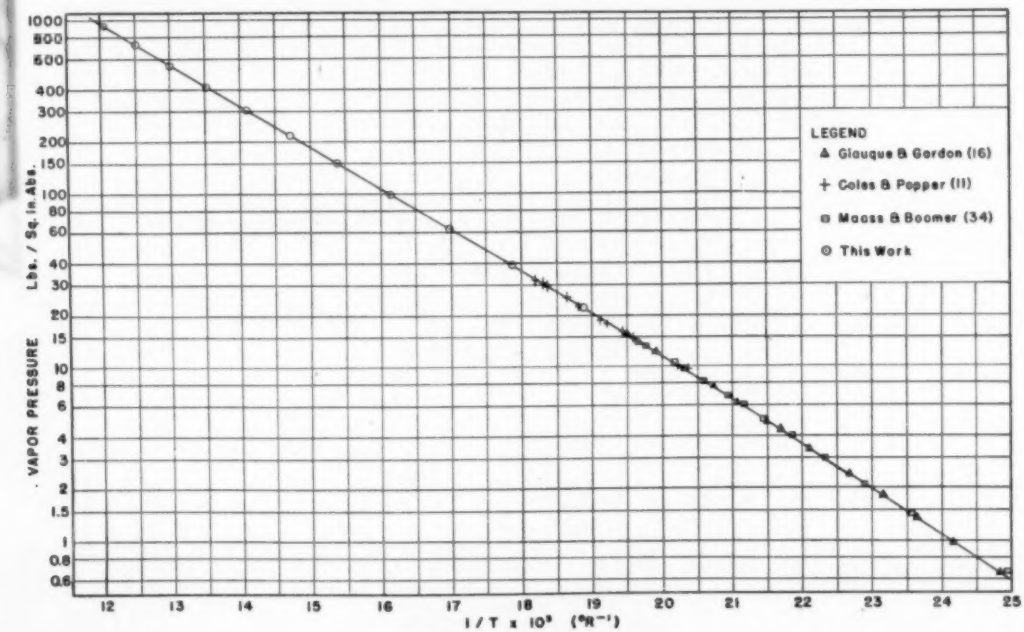

Fig. 5. Vapor pressure of ethylene oxide.

Rice (*30*) were chosen for use in the present calculations. The best moments of inertia for the molecule appear to be those by Cunningham, et al (*12*). The final calculated ideal gas properties are listed in Table 1. It should be noted that these values are in good agreement with those of Godnev and Morozov (*19*), because of the small differences in the constants used. The value of the zero point energy is calculated from the heat of formation at 25° C. (*41*) and the statistical enthalpy contributions to the compound and elements (*23*) above 0° K.

$$(\Delta H_f^\circ)_T = [(H_T^\circ - H_o^\circ) + H_o^\circ]_{C_2H_4O} - [2H_C^\circ + 2H_{H_2}^\circ + 1/2HO_2^\circ] \quad (2)$$

$$H_o^\circ = -12{,}190 - 2613 + 2(2{,}023) + 2(251) + 1/2(2{,}069) \quad (3)$$

$$H_o^\circ = -9{,}220 \text{ cal./g. mole} \quad (4)$$

Constants of the Beattie-Bridgeman equation of state (*5*) have been determined. In terms of lb./sq.in.abs., cu.ft./lb., and ° R., they are:

$$A_o = -30.0$$
$$a = 0.292$$
$$B_o = -0.150$$
$$b = 0.338$$
$$c = 5 \times 10^7$$

The equation with these constants fits the smoothed data with an average deviation of about 0.2% when applied 10-50 lb./sq.in. away from saturation and at volumes greater than 0.4 cu.ft./lb. It is not satisfactory closer to saturation conditions. The negativity of the constants is unusual, ethylene oxide behaving similarly to water in this respect (*3*).

Graphical methods were resorted to in the final evaluation of the pressure effect on enthalpy, entropy and fugacity coefficient. Methods of procedure have been well illustrated (*14*). The only unusual procedure in the present work occurred in the application of the Clapeyron equation to calculate latent heats. The accurate latent heat by Giauque and Gordon (*16*) at the normal boiling point was employed to establish the best slopes of the vapor pressure curve at lower temperatures, since several values for the slopes have been suggested.

The final calculated and smoothed values of volume, enthalpy, entropy and fugacity are listed in Tables 2 and 3. The enthalpy and entropy values are based on the assignment of zero to the enthalpy and entropy of saturated liquid ethylene oxide at 70° F. For use in rapid interpolation, where precision is not required, a pressure-enthalpy plot has been prepared (Fig. 6).

Since the greatest inconsistency must occur along the saturated liquid line (Fig. 6) the internal agreement of the calculated properties can be examined with the following equation:

$$s_T - s_{sat'd} = \int_{70°\text{F.}}^{T} \frac{dh}{T} + \int_{22.00\text{ lb./sq.in.abs.}}^{p} \frac{v_{Liq.}}{T}\,dp \quad (5)$$

applied along the saturated liquid line. This test indicates the average deviation within the tables to be no greater than 0.7 B.t.u./lb. for enthalpy, corresponding to 0.001 B.t.u./lb.—° R. for entropy.

Comparison of calculated enthalpies and entropies with those obtained by extrapolating the subboiling-point, liquid heat capacities (*16*) show agreement to be good to 0.2 B.t.u./lb. for the enthalpy change from 70 to 100° F., corresponding to a deviation of 0.0003 B.t.u./lb. ° R. for the change in entropy.

A comparison of the entropies calculated from the present work and those determined by Giauque and Gordon (*16*) from calorimetric data shows good agreement. The entropy values in cal./g. mole ° K. for the real gas at one atmosphere and the indicated temperatures are:

T(°K.)	S(Giauque, et al)	S (This work)
283.66	57.23	57.26
298.16	57.83	57.85

It is to be noted that the entropy from this work is dependent only on the vapor-phase volumetric data and spectroscopic values, and as such represents a completely independent check of Giauque and Gordon's results.

The agreement with the enthalpy data of Mock and Smith (*38*) is good to 2 B.t.u./lb.

TABLE 1. THERMODYNAMIC PROPERTIES OF ETHYLENE OXIDE

FOR THE IDEAL GAS STATE AT ONE ATMOSPHERE

The zero point energy (H_o°) = -9,220 cal/gmole

Temperature		C_p°	S°	$H^\circ - H_o^\circ$	$-\frac{F^\circ - H_o^\circ}{T}$
°F	°K	cal/gmole°K	cal/gmole°K	cal/gmole	cal/gmole°K
70	294.27	11.34	57.97	2565	49.26
100	310.94	11.96	58.61	2758	49.74
130	327.61	12.43	59.25	2961	50.21
160	344.27	12.99	59.88	3173	50.66
190	360.94	13.55	60.51	3394	51.10
220	377.61	14.11	61.13	3625	51.53
250	394.27	14.65	61.74	3862	51.95
280	410.94	15.20	62.36	4113	52.36
310	427.61	15.74	62.98	4371	52.76
340	444.27	16.27	63.60	4637	53.16
370	460.94	16.79	64.21	4914	53.55
400	477.61	17.28	64.81	5196	53.92

TABLE 2. PROPERTIES OF SATURATED ETHYLENE OXIDE

Temp. °F	Abs. press. lbs./sq.in.	Volume cu.ft./lb. Liq.	Volume cu.ft./lb. Evap.	Volume cu.ft./lb. Vap.	Enthalpy Btu./lb. Liq.	Enthalpy Btu./lb. Evap.	Enthalpy Btu./lb. Vap.	Entropy Btu./lb.°R Liq.	Entropy Btu./lb.°R Evap.	Entropy Btu./lb.°R Liq.
70	22.00	0.01820	5.447	5.465	0	245.3	245.3	0	0.4593	0.4593
100	38.60	0.01862	3.192	3.211	14.2	234.0	248.2	0.0258	0.4181	0.4439
130	63.55	0.01916	1.998	2.005	29.1	224.3	253.4	0.0518	0.3804	0.4322
160	99.70	0.01985	1.296	1.306	44.9	214.0	258.9	0.0781	0.3453	0.4234
190	150.0	0.02066	0.8585	0.8600	61.8	203.1	264.9	0.1049	0.3125	0.4174
220	217.8	0.02160	0.5975	0.6091	80.1	191.2	271.3	0.1317	0.2815	0.4130
250	306.3	0.02269	0.4047	0.4274	100.1	177.4	277.5	0.1585	0.2500	0.4085
280	419.1	0.02400	0.2770	0.2919	122.3	159.5	281.8	0.1869	0.2161	0.4050
310	559.5	0.02580	0.1863	0.2141	146.8	139.1	285.9	0.2210	0.1807	0.4017
340	731.0	0.0285	0.1220	0.1505	173.8	113.1	286.9	0.2547	0.1416	0.3963
370	936.7	0.0330	0.0697	0.1027	203.7	79.8	283.5	0.2910	0.0963	0.3873
384.4	1043	0.051	0	0.051	257	0	257	0.348	0	0.348

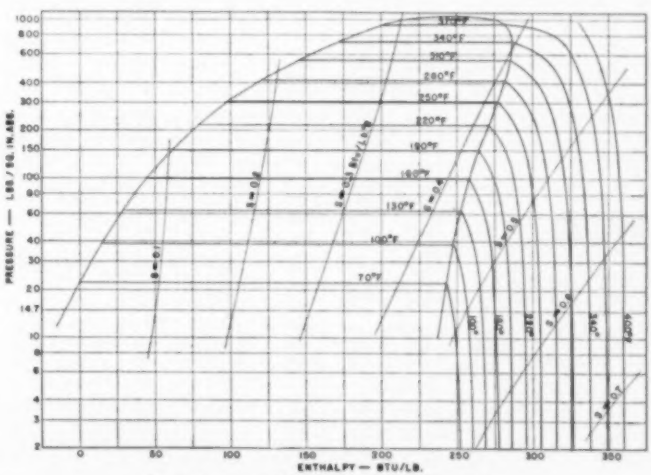

Fig. 6. Pressure-enthalpy diagram for ethylene oxide.

at low pressures, but deviates considerably more near saturation and high pressures, the present work indicating a greater ideality of ethylene oxide.

Considering the estimated accuracy of the p-v-T data and the over-all agreement with calorimetric data, it is believed that the enthalpies in the tables are not in error by more than 1 to 5 B.t.u./lb. The error in entropy is necessarily of the same order of magnitude, that is, 0.001 to 0.005 B.t.u./lb.$^{\circ}$ R. Four significant figures were retained in the tables because changes in the values, especially in the vapor state, probably can be determined with more accuracy than the estimate just shown. The greatest error would be expected in the critical region.

Acknowledgment

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TABLE 3. PROPERTIES OF SATURATED AND SUPERHEATED ETHYLENE OXIDE

p, absolute pressure, lbs./sq. in.; v, volume, cu. ft./lb.
h, enthalpy, Btu/lb.; s, entropy, Btu/lb.-°R
Parenthesis figures after temperatures are saturation pressures

p	70°F (22.00) v	h	s	f/p	100°F (36.60) v	h	s	f/p
Sat'd vapor	5.465	243.3	0.4593	0.942	3.211	248.2	0.4439	0.928
Sat'd liquid	0.01820	0	0	-	0.01862	14.2	0.0258	-
0	-	252.7	-	1.000	-	260.6	-	1.000
1	138.7	252.4	0.6138	0.998	136.1	260.4	0.6284	0.998
3	42.72	251.8	0.5634	0.994	45.22	259.9	0.5782	0.995
5	25.51	251.2	0.5393	0.989	27.04	259.5	0.5545	0.992
10	12.56	249.5	0.5055	0.977	13.40	256.2	0.5213	0.984
14.7	8.434	247.5	0.4848	0.966	9.032	256.9	0.5020	0.975
20	6.087	244.8	0.4662	0.949	6.556	255.1	0.4854	0.966
30					4.253	251.8	0.4608	0.947

p	190°F (150.0) v	h	s	f/p	220°F (217.8) v	h	s	f/p
Sat'd vapor	0.8600	264.9	0.4174	0.873	0.6091	271.3	0.4130	0.845
Sat'd liquid	0.02066	61.8	0.1049	-	0.02160	80.1	0.1317	-
0	-	286.3	-	1.000	-	295.9	-	1.000
1	158.1	286.4	0.6715	0.999	165.4	295.8	0.6856	0.999
3	52.62	286.2	0.6218	0.998	55.19	295.7	0.6360	0.998
5	30.04	286.0	0.5985	0.996	32.99	295.5	0.6127	0.996
10	15.69	285.6	0.5667	0.992	18.44	295.2	0.5811	0.993
14.7	10.63	285.1	0.5489	0.988	11.15	294.8	0.5634	0.989
20	7.913	284.6	0.5344	0.983	8.157	294.4	0.5491	0.986
30	5.141	283.6	0.5150	0.975	5.398	293.7	0.5301	0.978
40	3.821	282.6	0.5007	0.967	4.018	292.9	0.5163	0.971
60	2.502	280.4	0.4797	0.950	2.638	291.4	0.4963	0.957
80	1.840	277.8	0.4636	0.934	1.947	289.7	0.4816	0.943
100	1.438	274.8	0.4498	0.918	1.532	288.0	0.4696	0.929
150	0.8800	264.9	0.4174	0.873	1.104	282.5	0.4450	0.894
200					0.6858	274.5	0.4220	0.858

p	250°F (306.8) v	h	s	f/p	280°F (419.1) v	h	s	f/p
Sat'd vapor	0.4274	277.5	0.4093	0.811	0.3019	281.8	0.4050	0.778
Sat'd liquid	0.02269	100.1	0.1593	-	0.02400	122.3	0.1889	-
0	-	305.6	-	1.000	-	315.9	-	1.000
1	172.8	305.5	0.6997	0.999	180.1	315.8	0.7139	0.999
3	57.52	305.4	0.6501	0.998	59.96	315.7	0.6642	0.998
5	34.47	305.3	0.6269	0.997	35.94	315.6	0.6410	0.997
10	17.18	305.0	0.5953	0.994	17.92	315.3	0.6100	0.995
14.7	11.76	304.7	0.5777	0.991	12.16	315.1	0.5919	0.992
20	8.535	304.4	0.5635	0.988	8.910	314.7	0.5787	0.989
30	5.653	303.7	0.5446	0.981	5.907	314.2	0.5589	0.984
40	4.212	303.1	0.5310	0.975	4.405	313.6	0.5454	0.978
60	2.771	302.0	0.5114	0.963	2.905	312.4	0.5260	0.968
80	2.050	300.5	0.4972	0.951	2.152	311.3	0.5119	0.957
100	1.617	299.1	0.4858	0.939	1.700	310.1	0.5009	0.946
150	1.087	295.5	0.4639	0.908	1.097	307.0	0.4798	0.920
200	0.7434	291.0	0.4461	0.878	0.7944	303.5	0.4633	0.893
300	0.4402	278.5	0.4115	0.815	0.4866	295.2	0.4364	0.840
400					0.3249	283.8	0.4101	0.787

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Discussion

Anonymous: You noticed polymerization at 220° F. Did you notice it at any temperatures below that?

J. M. Smith (Purdue University, Lafayette, Ind.): No. Within the precision of our volumetric data and over the time interval that we covered there was no evidence of volume change with time below 220° F. It might be mentioned that at a temperature of 300° F., the volume change amounted to 0.4% per hour and increased in accordance with an exponential function at temperatures higher than that.

Anonymous: I'm surprised it wasn't faster than that at 300° F. What was the next lowest temperature? In other words, you say there was nothing below 220° F. but what was the next lowest temperature and what was the pressure effect on that?

J. M. Smith: We operated in 30° temperature intervals so the next lowest was 190° F. We found the pressure effect was not such that it indicated polymerization was a homogeneous reaction. Instead, the rate appeared to be a function of the surface available to the ethylene oxide. The effect of pressure in increasing the concentration of the molecules within the homogeneous region did not increase the polymerization.

E. W. Comings (Purdue University, Lafayette, Ind.): In connection with the experimental technique, the difficulty from the contact of mercury with platinum apparently is a common one in work of this sort. Hagenbach (*1*) recently completed measurements on p-v-T properties of mixtures of nitrogen and ethylene and encountered somewhat the same sort of difficulty. Maverick (*2*) made some measurements with the express purpose of investigating the reasons for the poor contact between mercury and platinum. The conclusion was reached that there were two sources of error. One has to do with the original purity of the mercury and it seems that it is difficult to take sufficient precautions in purifying mercury to insure good contact. Dr. Michels (*3*), of Amsterdam, has developed careful techniques for the purification of mercury. The second source of error Maverick found was that it is rather easy to contaminate the mercury. In the experiments which he conducted he used an aluminum gasket to seal his bomb and at one time removed quite a large amount of a white powder from the surface of the mercury when the bomb was opened. It was found that whereas mercury and aluminum seldom react, if the surface of the aluminum is scratched, then the surface aluminum oxide coating is removed and reaction or amalgamation between the aluminum and the mercury becomes rather easy. A piece of sheet aluminum outside of the bomb was coated with a drop of mercury and then the surface was scratched. Little trees of aluminum oxide grew up in a period of 10-15 min. In that time a layer ¼-in. thick or so will form. This indicates a serious source of contamination. The mercury may become contaminated with the aluminum in the gaskets and also with small amounts of alloying constituents such as the copper contained in the aluminum.

C. C. DeWitt (Michigan State College, E. Lansing, Mich.): The remarks about the action of mercury on aluminum check with my own experience in the same general type of work. About ten years ago we had occasion to make similar observations on another gas and we observed that if we scratched the aluminum and put it into air, it would react as you have indicated. We found this action to be even greater when we aerated aluminum in water. The presence of water vapor in the air seemed to exert a profound effect upon the velocity of the formation of this tree of aluminum oxide.

TABLE 3 (continued)

p	310°F (559.5) v	h	s	f/p	340°F* (731.0) v	h	s	f/p
Sat'd vapor	0.2141	285.9	0.4017	0.743	0.1509	286.9	0.3963	0.704
Sat'd liquid	0.02580	146.8	0.2210	-	0.0285	173.8	0.2547	-
0	-	326.4	-	1.000	-	337.8	-	1.000
1	197.4	326.4	0.7280	1.000	194.7	337.8	0.7421	1.000
3	62.40	326.3	0.6784	0.999	64.85	337.7	0.6925	0.999
5	37.41	326.2	0.6552	0.998	38.87	337.6	0.6693	0.998
10	18.66	325.9	0.6237	0.995	19.39	337.4	0.6379	0.996
14.7	12.67	325.7	0.6068	0.993	13.17	337.2	0.6204	0.994
20	9.264	325.4	0.5920	0.990	9.655	337.0	0.6062	0.991
30	6.159	324.9	0.5733	0.986	6.409	336.6	0.5877	0.987
40	4.597	324.0	0.5599	0.981	4.785	336.1	0.5744	0.983
60	3.054	323.4	0.5407	0.972	3.162	335.3	0.5554	0.974
80	2.255	322.4	0.5288	0.962	2.350	334.4	0.5417	0.966
100	1.763	321.4	0.5180	0.953	1.845	333.5	0.5310	0.958
150	1.157	318.8	0.4954	0.930	1.215	331.3	0.5110	0.936
200	0.8429	316.1	0.4800	0.907	0.8870	329.1	0.4962	0.916
300	0.5259	310.1	0.4563	0.861	0.5605	324.4	0.4741	0.875
400	0.3642	303.0	0.4365	0.816	0.3950	320.4	0.4581	0.834
500	0.2610	292.7	0.4157	0.770	0.2936	314.0	0.4423	0.797
700					0.1663	291.3	0.4035	0.717

p	370°F* (936.7) v	h	s	f/p	400°F* v	h	s	f/p
Sat'd vapor	0.1027	283.5	0.3865	0.661	-	-	-	-
Sat'd liquid	0.0330	205.7	0.2902	-	-	-	-	-
0	-	348.6	-	1.000	-	360.1	-	1.000
1	202.0	348.6	0.7560	1.000	209.3	360.1	0.7703	1.000
3	67.29	348.5	0.7064	0.999	69.72	360.0	0.7207	0.999
5	40.34	348.4	0.6833	0.998	41.80	359.9	0.6976	0.999
10	20.13	348.3	0.6518	0.996	20.86	359.8	0.6663	0.997
14.7	13.67	348.1	0.6344	0.994	14.16	359.7	0.6489	0.995
20	10.02	347.9	0.6204	0.992	10.39	359.5	0.6349	0.993
30	6.656	347.6	0.6019	0.988	6.902	359.2	0.6165	0.989
40	4.973	347.2	0.5886	0.984	5.157	358.9	0.6033	0.986
60	3.288	346.3	0.5698	0.976	3.412	358.3	0.5845	0.979
80	2.446	345.7	0.5563	0.969	2.539	358.0	0.5714	0.972
100	1.940	345.0	0.5456	0.961	2.016	357.3	0.5606	0.965
150	1.286	343.2	0.5263	0.942	1.336	355.9	0.5413	0.948
200	0.929	341.4	0.5120	0.923	0.967	354.5	0.5276	0.931
300	0.590	337.7	0.4910	0.886	0.617	351.6	0.5076	0.897
400	0.420	333.8	0.4752	0.850	0.442	348.6	0.4926	0.864
500	0.316	329.4	0.4618	0.814	0.335	345.5	0.4813	0.831
700	0.193	318.5	0.4376	0.744	0.212	339.3	0.4620	0.766
900	0.117	299.3	0.4076	0.674	0.140	333.0	0.4475	0.704

*based on extrapolated volumetric data.

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METALS POISONING OF FLUID CRACKING CATALYST

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THE catalytic cracking process has become increasingly important to the petroleum industry as the competitive demand for higher octane motor fuel has developed. The function of the catalytic cracking process is to convert a hydrocarbon fraction known as gas oil into gasoline—fuel gas and coke being produced as by-products. Relative yields of gasoline and by-product fuels may be influenced by the quality of the catalyst. The term "catalyst selectivity" denotes the inherent catalytic properties that control these relative yields. A catalyst of good selectivity gives a high yield of gasoline, possibly as high as 93 bbl./100 bbl. of gas oil actually converted. Conversely, under identical cracking conditions, a catalyst of poor selectivity will be shown to result in a gasoline yield as low as 82 bbl./100 bbl. converted. On a unit producing 10,000 bbl. per day of catalytic gasoline, such a reduction in yield can represent a monetary loss of several thousand dollars per day.

Investigations in the field of catalytic properties have shown that deterioration of catalyst selectivity with time can be caused by the presence of relatively small quantities of contaminants in the feed. Known catalyst "poisons" that adversely affect selectivity are sulfur (*3, 4, 5*) and metals. Iron, nickel, vanadium, and copper are the major metallic contaminants commonly found in gas-oil feeds (*5*). The metallic compounds are relatively nonvolatile and are found in greatest concentrations in the higher boiling crude fractions.

To increase the production of catalytic gasoline, the refiner may wish to augment the usual catalytic cracking feed with contaminating marginal streams, or even with whole crude. However, the resulting decline in catalyst selectivity might well make such a move disadvantageous in the long run. Although it is possible for the refiner to control the selectivity deterioration by continually discarding a fraction of the catalyst in the unit and replacing it with fresh material of good selectivity, this expedient increases operating costs because of the additional catalyst consumption. To decide on the most profitable operation of his catalytic cracking unit, the refiner must determine quantitatively the extent of selectivity deterioration that would be encountered with a given contaminating feed stock, and he must determine the amount of additional catalyst discard that would be needed to maintain satisfactory selectivity.

Operation of a fluid catalytic cracking unit at the Sugar Creek refinery of the Standard Oil Company (Indiana) has provided data on the contaminating effect of metals in cracking feed. While this experience has not resulted in a universal solution to the selectivity problem, the results should be of general interest to other refiners.

At Sugar Creek three different high-metals heavy gas oils, available at various times over a 2-year period, were used successively as marginal cracking stocks. During this period, two separate batches of catalyst were employed in the cracking unit. The selectivity effects observed under these conditions, as well as the quantitative methods developed for predicting selectivity degradation and catalyst requirements for selectivity control, form the basis of this paper.

Apparatus

The cracker is a fluid-catalyst unit with a design feed rate of 25,000 bbl./day. Figure 1 shows a simplified schematic diagram of the unit. The principal vessels are the reactor, in which the cracking reaction takes place; the regenerator, in which by-product coke is burned off the catalyst; and the fractionator, in which the reaction products are separated for further refinery processing.

In the continuous cracking process, cold gas-oil feed from tankage is preheated by heat exchange with hot oil streams and by a fired pipe-still heater. The partially vaporized oil then picks up hot catalyst of low coke content from the regenerator. The heat of the catalyst completes the vaporization of the feed and also supplies heat for the vapor-phase reaction. Vaporized products pass overhead from the reactor to the fractionator, and coke-laden catalyst is continuously withdrawn from the reactor through a steam stripper for removal of hydrocarbons. This spent catalyst is picked up by an air stream and carried back to the regenerator, where the coke deposit is removed by burning. Entrained catalyst is separated from the exit-gas streams by means of multistage cyclone separators in the reactor and regenerator vessels.

Slurry oil, which is the bottom fraction from the reactor products, is totally recycled to the reactor feed line. In addition, heavy gas oil is recycled to the unit to the extent of 10 to 15 vol. % of the fresh feed. As metals have been found in both the slurry and the heavy gas oil, it is probable that recycling results in greater catalyst contamination per pound of metal in the fresh feed than would be the case with single-pass operation.

"Natural" catalyst, an acid-activated Montmorillonite clay, (*4, 7*) was used throughout the period of operation dealt with herein. All data and conclusions presented are necessarily restricted to this type of catalyst.

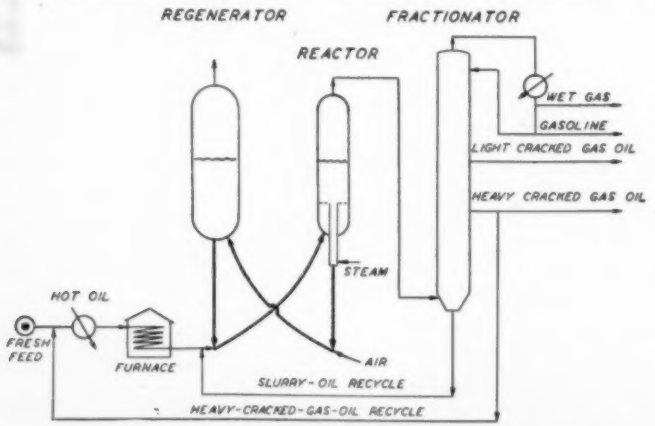

Fig. 1. Fluid catalytic cracking.

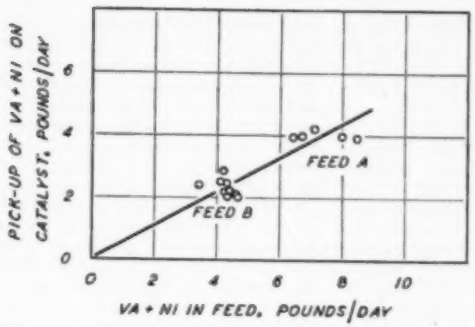

Fig. 2. Metals pickup on catalyst vs. metals in feed.

Cracking Feeds

The fresh feed to catalytic cracking is a mixture of all refinery virgin and coke-still gas-oil streams from predominantly Mid-Continent crude oil, roughly 20% being high-sulfur crudes of Wyoming and West-Texas origin. Approximately 90% of the feed is clean, low-metals gas oil, while the remainder is the high-metals heavy gas oil currently available. The three marginal heavy gas oils were blended with clean gas oil to provide three feeds, designated *A*, *B*, and *C* and used in sequence over the 2-year period. The three marginal gas oils were of the same origin and boiling range and differed only in their metals contents.

Spectrographic analyses were run on ashed samples of the feed and on samples of the catalyst for calcium, copper, iron, lead, magnesium, manganese, nickel, sodium, titanium, and vanadium. Comparison of the amount of each metal in the feed with the rate of pick-up of each metal by the catalyst indicated that a correlation between metal content in the feed and catalyst contamination was possible only in the cases of nickel and vanadium. These two metals have, therefore, been assumed to be the key to the catalyst contamination experienced. The analytical data given in Table 1 show that the three feeds contain relatively large amounts of nickel and vanadium, as compared with the clean gas oil comprising the major portion of each feed. In subsequent cracking operations with feeds *A* and *B*, metals balances indicated that approximately half of the total vanadium and nickel in the feeds was accumulated on the catalyst. This effect is illustrated in Figure 2, where the pick-up of metals on the catalyst is plotted against the metals input from the feed.

Carbon Factor and the Indiana Relative Activity Test

Before presenting the selectivity effects observed on the commercial unit with the three feeds described above, it is necessary to define the criterion of catalyst selectivity employed. Because the operating conditions of the unit, as well as the inherent properties of the catalyst, will have a pronounced effect upon the relative yield of gasoline, a standardized laboratory test has been used to indicate the selectivity of the catalyst. Coke-producing factor (or carbon factor), as obtained in the laboratory by the Indiana relative-activity testing procedure, was the index of selectivity used.

The Indiana relative-activity test is described fully by Shankland and Schmitkons (*6*). Briefly, the laboratory procedure employs a 1-hr. cracking run, downflow through a nonfluidized bed of the powdered catalyst sample, with cracking conditions constant. Carbon factor is defined as the ratio of the carbon yield on the catalyst sample as tested to that on a reference catalyst at the same conversion. Carbon factor, as used hereafter, refers to this laboratory test rather than to plant coke yield, although, as will be seen later, carbon factors correlate well with plant yields.

Effects of the Various Feeds upon Carbon Factor. With carbon factor as a measure of the inherent selectivity of the catalyst in the commercial unit, Figure 3 demonstrates the observed effects of the three different feed stocks. At the start-up on the first catalyst batch, feed *A*—the feed with the highest metals content—was charged to the unit. Throughout the period of the data, catalyst was added as make-up to offset

TABLE 1.—APPROXIMATE METALS CONTENT OF CRACKING FEEDS

Metals, p.p.m.	Clean gas oil	Feed *A*	Feed *B*	Feed *C*
Nickel	<0.05	0.35	0.40	0.20
Vanadium	0.06	1.10	0.50	0.45
Total	<0.11	1.45	0.90	0.65

normal catalyst losses, but there was no intentional catalyst discard. As will be noted, carbon factor rose rapidly and continued to rise until after feed *B* was introduced. For a short period after the lower metals feed *B* was started to the unit, carbon factor continued to rise to a value of 3.5 and then dropped sharply to 2.4. With continued operation on feed *B*, carbon factor began a second but more gradual rise. After a total of 360 days on stream and with a carbon factor of 2.9, the first catalyst batch was dumped and replaced with a fresh charge having a 1.0 carbon factor. As feed *B* was continued on this fresh catalyst charge, contamination was still observed. The rise in carbon factor, however, was at a decidedly lower rate than on the initial catalyst with feed *A*. Finally, feed *C* was started to the unit. Again there was a lag followed by a sharp drop in carbon factor. Limited availability of feed *C* forced the discontinuance of the study at this point.

Effects of Carbon Factor upon Gasoline Yield. Thus far, the historical behavior of the catalyst exposed to the three feeds has been sketched. Of interest to the refiner, however, are data showing the effects of selectivity deterioration upon commercial gasoline yields. Uniform operating procedures at the cracking unit and constant routing of refinery streams during the period studied provided a consistent basis for preparing generalized yield correlations from more than 150 sets of data available. In the basic correlation work, carbon factor was used as a parameter. For this presentation, the independent effects of carbon factor have been isolated in a cross-plot (see Figure 4).

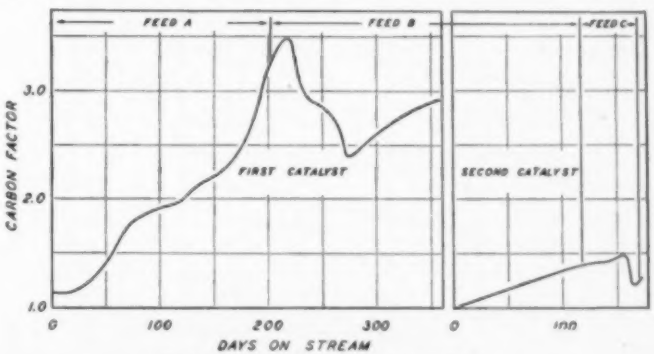

Fig. 3. Catalyst carbon factor vs. days on stream.

The upper curve in Figure 4 shows the effect of carbon factor upon gasoline yield, with the yield expressed as volume per cent on feed disappearance (total feed minus total cracked gas-oil product). Gasoline yield dropped from 93% to 82% on feed disappearance as carbon factor rose from 1.0 to 3.0. By-product fuel increased by a corresponding amount, the increase being approximately equally shared by coke and fuel gas.

Two effects of carbon factor upon gasoline quality are also shown in Figure 4. The research octane number (*1*) of the total gasoline increased a little more than one unit over the carbon-factor range. Similarly, the Reid vapor pressure (*2*) of total gasoline increased about two pounds. The octane and vapor-pressure effects of carbon factor are economic factors to the refiner. The octane number of catalytic gasoline affects requirements for tetraethyl lead, and changes in gasoline vapor pressure necessitate adjustments in the processing of refinery butane.

The data of Figure 4 made it possible to evaluate economically the deterioration of the commercial yield structure in terms of catalyst carbon factor. With this evaluation available, the other item necessary for a complete economic analysis of the selectivity problem was a method of predicting catalyst carbon factors for the various feeds that would take into account the carbon-factor control permitted by intentional catalyst discard.

Prediction of Catalyst Requirements for Carbon-Factor Control. The conclusions presented thus far have followed directly from the plant data. However, the prediction of catalyst carbon factor, taking into account the control afforded by increases in addition rate above those of the plant data, requires a theoretical correlation basis. The method developed for this prediction is based upon the concept of average catalyst age, initially developed for use in catalyst-activity studies. If catalyst age is defined as the on-stream time that a given ton of catalyst has been in the unit, an average catalyst age for the entire inventory can be calculated. Selectivity deterioration for a given rate of metals input can then be considered a function of catalyst age. In the present calculation of average catalyst age, fresh-catalyst additions were corrected to eliminate the "fines" that would promptly be lost from the unit, but no attempt was made to rectify the small error introduced by assuming that the additional fines developed in the unit (and similarly lost) were of the same age as the average catalyst.

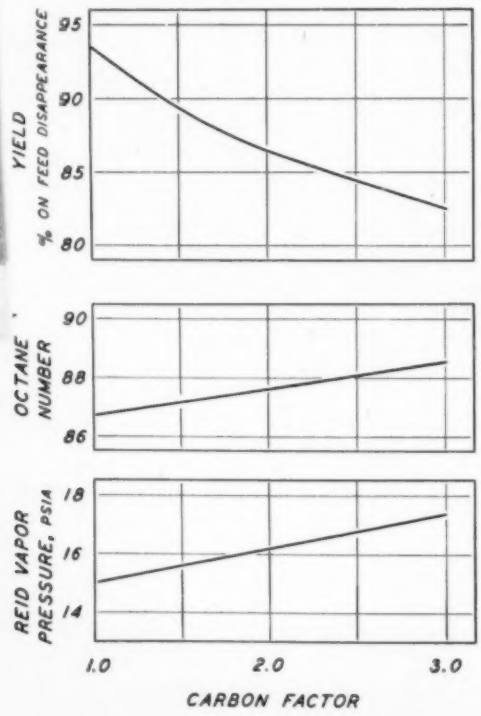

Fig. 4. Effect of carbon factor on gasoline yield and quality—53% conversion.

When replotted on the basis of average catalyst age, as shown in Figure 5, the carbon-factor data of Figure 3 serve as a basis for estimating contamination curves for the three feeds employed. A contamination curve for a given feed defines the relationship between carbon factor and average catalyst age that would obtain if the feed were cracked over a catalyst that was initially at 1.0 carbon factor. For a contaminant-free feed, it is assumed that the curve would be a straight line at 1.0 carbon factor. For feed *A*, the curve was based upon the data from the first batch of catalyst. This catalyst actually had a carbon factor of 1.14 at the start of the investigation; therefore, the contamination curve for feed *A* was placed slightly below the points in order that the curve might go through the origin, as demanded by definition. The early points on the second batch of catalyst formed the lower portion of the feed-*B* curve, while the final portion of the data on the first catalyst batch served as a guide in extrapolating to higher values. The final points of the upper curve thus represents the upper limit of carbon factor that would have been obtained if feed *B* had been cracked over a fresh batch of catalyst all the way to the same catalyst age. Actual data on feed *C* were meager; however, the line shown is believed to be a fair approximation, considering the pattern previously established and considering the comparative metals content of the three feeds.

The foregoing interpretation of selectivity data is based upon the fact that poisoning metals can exist on the catalyst in an active or inert state. Metals content of the catalyst, alone, is not an indication of carbon factor. For example, after feed *B* was substituted for feed *A*, the actual metals content of the catalyst (nickel and vanadium) continued to increase. Carbon factor continued to rise for a brief period and then fell. Rates of metals activation and deactivation, as well as the rate of deposition, are believed to be factors contributing to the instantaneous selectivity of the catalyst. The preceding extrapolations were made according to this theory and assume that, for a given feed, carbon factor at infinite catalyst age will be the same for any catalyst regardless of its previous metals history.

The relationships established in Figure 5 were used to predict the catalyst requirements for control of carbon factor. Although these contamination curves are based upon data obtained while catalyst age was increasing, it was assumed that the curves would remain valid if the catalyst age were held constant at some lower equilibrium value by increasing the addition rate above

make-up requirements. It was also assumed that a secondary effect of activity upon carbon factor, associated with the increased addition rate, would be small and could be neglected. With these assumptions, it was possible to arrive at the catalyst requirements for selectivity control as a function of equilibrium carbon factor.

The curves in Figure 6 present the predictions of make-up catalyst requirements for the three feeds. The catalyst additions are on a fines-free basis and are expressed as tons per thousand barrels of fresh feed, rather than per pound of metal. It is not felt that available data warrant a generalized relationship on the latter basis. However, it is of interest to note that for feeds *A* and *B*, an average of 2.4 tons of catalyst (fines-free) per pound of nickel plus vanadium in the feed were required to hold a 1.2 carbon factor.

Optimum Operation

Figures 4 and 6 enabled the Sugar Creek refinery to arrive at optimum operation of the catalytic cracking unit from the selectivity standpoint. Figure 4 presents the gasoline-yield structure associated with any carbon factor, and Figure 6 shows the catalyst required to operate at any carbon factor for each feed.

The determination of optimum operation for each feed required only an economic balance between catalyst costs to maintain a low carbon factor and the yield penalty that is incurred if carbon factor rises. An evaluation of the relative economics in sending the three different feeds to the catalytic cracking unit was possible by a comparison of the optimum points of operation for each. This economic evaluation revealed the magnitude of the incentive for reducing the metals content of cracking feeds through other refinery processes.

Acknowledgments

The authors wish to acknowledge the assistance of many associates in both the Sugar Creek and Whiting laboratories of the Standard Oil Company (Ind.). Especial thanks are extended to D. E. Jones, B. E. Olson, C. O. McKinney, and W. A. Weaverling, who provided much of the basic data, and to R. V. Shankland, A. L. Conn, and P. C. White, who provided pilot-plant and spectrographic information used in interpreting the results.

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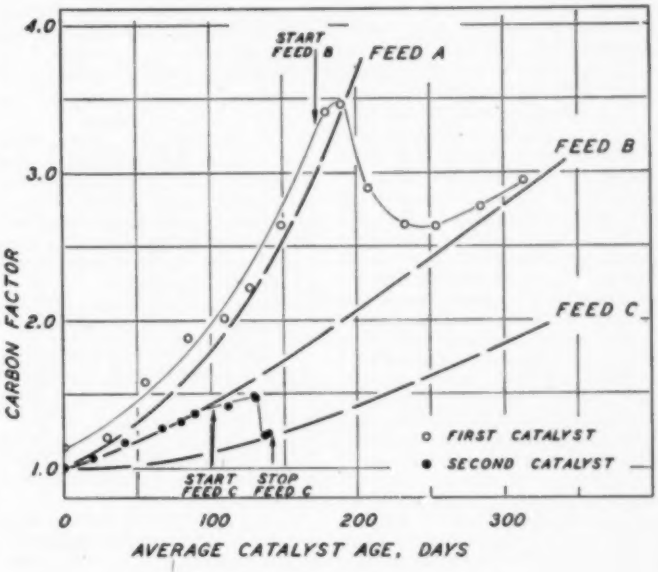

Fig. 5. Carbon factor as a function of catalyst age.

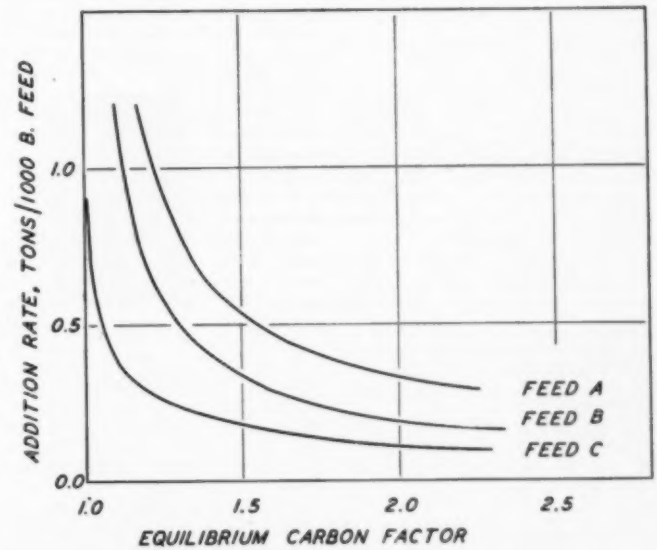

Fig. 6. Catalyst addition rates for selectivity control.

Discussion

G. P. Masologites (Atlantic Refining Co., Philadelphia, Pa.): What other factors were taken into consideration? For example, steam partial pressure, temperature, metals other than those shown—have you looked into these?

B. J. Duffy: A possible effect of steam partial pressure upon catalyst selectivity was considered, but it was found that it was not possible to control carbon factor by increasing steam rates to any reasonable value. At all times the total of the reactor-stripping steam plus the hydration steam to the standpipe hoppers in the regenerator was maintained above 20 lb./ton of circulating catalyst. Values as high as 49 lb./ton failed to check the rise in carbon factor when operating on feed *A*. After operation on feed *B* had commenced, the steaming rate was increased from about 20 to 40 lb./ton of circulating catalyst. On this occasion there was a slight drop in carbon factor from 2.65 to 2.33, but as soon as the steam rate was returned to 20 lb./ton, the carbon factor rose quickly again to 2.65. These experiences led to the conclusion that the contamination was of such a nature that it could not be prevented by steaming. The only other variable over the period of the data was the metals content of the feed, and the response of carbon factor to the metals content was convincing evidence that the metals were responsible.

G. P. Masologites: It is hard to believe that iron did not come into the picture to at least the extent that vanadium and the other metals did.

B. J. Duffy: We cannot say definitely that iron has not been a factor in the catalyst contamination, but the spectrographic data on the catalyst indicate that it has not. The data show that iron on the catalyst in the unit was decreasing throughout the period of the rise in carbon factor. The only metals that showed an increase in metals corresponding to the rise in carbon factor were nickel and vanadium.

G. P. Masologites: Approximately what catalyst-addition rates in tons per day were maintained throughout the tests?

B. J. Duffy: Addition rates decreased throughout each run. On a fresh catalyst charge, addition rate was about 5 tons per day. Over a period of a year, the addition rate would decrease to about ½ ton per day. Incidentally, the unit is operating considerably below coke-burning capacity—accounting for the very low catalyst loss.

R. P. Trainer (Shell Oil Co., Wood River, Ill.): I'd like to ask if the slurry-recycle rates were varied during this study and whether you were able to show what effect the variation of slurry would have on the metallic buildup on the catalyst.

B. J. Duffy: Slurry recycle was constant over the entire period at about 8 vol. % on fresh feed. For this reason we have no basis for predicting the effect of slurry recycle upon metals buildup.

R. P. Trainer: Did you determine the metallic content of the slurry?

B. J. Duffy: The presence of contaminating metals in both the slurry and heavy-gas-oil-recycle streams was confirmed by spectrographic analyses. However, because recycle was constant throughout, data are not available that would enable a prediction of how much of the contamination is due to recycling. We can only offer the opinion that there is some increase in metals pickup by the catalyst with recycling.

R. P. Trainer: How many stages of cyclones did you have in your reactor?

B. J. Duffy: There are two cyclones in series in each of four parallel sets.

H. E. Rasmussen (Socony Vacuum Laboratories, Paulsboro, N. J.): You show roughly 50% of your metals going into the catalyst. What is your theory as to what happened to the other 50% in the feed stock?

B. J. Duffy: First, I should like to comment on the metals data of Figure 2 that show roughly 50% of the metals being picked up by the catalyst. Possibly this figure should be considerably lower. The spectrographic analyses on oil were run on ashed samples, and there is a good possibility that there was volatilization of some of the metals during ashing. Standardized techniques may account for the fairly nice correlation obtained. More recent work indicates that possibly the oil analyses may be low by a factor of 3 to 5. The pickup of metals by the catalyst could be as low as 10% of the input.

H. E. Rasmussen: In that case, what happens to the 90%?

B. J. Duffy: Our data have shown metals in the gas oil leaving the unit, but we have not had much success in completing balances for metals. We should be interested in the experience of others in this regard.

H. E. Rasmussen: It is very possible that a good part comes out with the flue gases during regeneration, although I can't substantiate that in any way. Have you any correlation between synthetic and natural catalyst? Is one better than the other?

B. J. Duffy: We have recently started operating on synthetic catalyst but have not as yet developed any data of this nature on the synthetic catalyst.

W. C. Offutt (Gulf Research & Development Co., Pittsburgh, Pa.): Since carbon factor was reduced by the use of hydration steam, I think that the metals analysis on the feed during this period might be pertinent. If the metal content of this feed was comparable to that of feed *A*, for example, it would indicate that the carbon-factor increase as a result of feed *A* was due to sulfur poisoning and could also have been combatted with hydration steam.

B. J. Duffy: Sulfur poisoning, in the ordinary sense, was not the cause of the contamination experienced, but there may have been a secondary effect of sulfur upon the poisoning by metals. Sulfur content in the charge was constant at 0.5 to 0.7% throughout the period of the data. No correlation was found between the carbon-factor behavior and sulfur content of the feed. Further, although the data are not included in the paper, the initial catalyst batch was used material that had been sulfur-poisoned. Hydration steam to the standpipe hoppers in the regenerator quickly brought the carbon factor on this batch down from 1.7 to 1.1. Subsequent to this, carbon factor began its rise due to metals contamination, and steaming at high rates was of no benefit in checking the rise.

When we consider that steaming did have a slight beneficial effect upon carbon factor when operating on feed *B*, a tie-in between sulfur and metals poisoning is indicated. We do not think that the steam was removing metals from the catalyst during this period. Metals content of the catalyst, alone, is not an indication of carbon factor. All data point to the conclusion that the poisoning metals can exist on the catalyst in an active or inert state. For example, after feed *B* was substituted for feed *A*, the actual metals content of the catalyst (nickel and vanadium) continued to increase, but carbon factor fell. A rate of metals activation and deactivation as well as the rate of deposition could all be factors contributing to the instantaneous selectivity of the catalyst. Sulfur and steam rates and possibly temperature could all have an influence on the activation and/or deactivation rates. Phenomena of this type could explain the behavior observed on feed *B*. On feed *A*, the contamination rate may have been so great that it prevented the detection of a similar effect with the steam rates in use. It is only in this possible secondary sense that sulfur could be considered as contributing to the selectivity deterioration encountered.

(Presented at A.I.Ch.E. Kansas City (Mo.) Meeting.)

PURIFICATION OF AMMONIA SYNTHESIS GAS

W. W. YEANDLE and G. F. KLEIN

Spencer Chemical Company, Pittsburg, Kansas

CONTINUOUS and efficient production of synthetic ammonia demands that the synthesis gas mixture be essentially free of carbon oxides, sulfur-containing compounds, and water vapor, all of which are usually present in the raw gas supply. The purpose of this paper is to explain the commercial processes for purification and to describe typical equipment installations

Modern techniques for purification of ammonia synthesis gas are quite diverse and process design is generally dictated by the demands of the synthesis and type of hydrogen gas production employed, the latter of more significance. Gas for ammonia synthesis is produced commercially by: (1) Water gas from coke and steam, (2) Reforming of natural gas with steam, (3) Electrolytic decomposition of water, and (4) Miscellaneous by-product sources.

Problems of gas purification are negligible in the electrolytic type of gas production.

In the natural gas and coke processes, it is inherent that production of hydrogen is accompanied by production of carbon oxides which must be extracted prior to synthesis of the nitrogen and hydrogen to ammonia. The poisonous action of carbon oxides on conventional ammonia synthesis catalysts and the possible formation of ammonium carbamates and carbonates in lines and equipment demand that purification be dependable and adequate.

The water-gas shift is used almost universally to convert the bulk of carbon monoxide with steam to carbon dioxide and hydrogen, the reaction being catalytically promoted by iron oxide and alkaline earth oxides. In general, this process step is best effected by passing the gases over the catalyst in the temperature range of 350-500° C. with steam adjusted for optimum conversion, and at space velocities generally of the order of 300-600 reciprocal hours. There is variation in equipment design and the reaction itself has variables, the study of which is outside the scope of this paper. In all cases, however, it is desirable to promote this reaction to the maximum possible extent for the reasons that each mole of carbon monoxide reacting with steam produces a mole of usable hydrogen and a mole of carbon dioxide, and carbon dioxide is extracted at lower cost and more simply than is carbon monoxide. Typical analyses of synthesis gas prepared from coke and natural gas are shown in Table 1.

The removal of sulfur-bearing compounds from synthesis gas is effected by various means. Generally, hydrogen sulfide and mercaptans are believed to poison permanently the nickel containing catalysts used in reforming hydrocarbon gases to hydrogen and carbon oxides, and are therefore removed from the hydrocarbon upstream of the reformer. Catalytic conversion of the mercaptan to hydrogen sulfide followed by caustic absorption typifies this operation. Removal of hydrogen sulfide from gas produced in steam-coke plants can be, and generally is, effected in the same equipment used for carbon dioxide and carbon monoxide removal. Complete elimination of this constituent is incidental to carbon monoxide removal in the copper ammonium formate or acetate purification operation featured in many plants.

In Figure 1(A), generally typical of low-pressure syntheses, the impure gas is compressed and at a selected interstage pressure, usually 250 to 400 lb./sq.in. gage, is passed through either a water or alkylamine solution absorption tower for removal of carbon dioxide. Some carbon dioxide, approximately 0.5-1.0%, remains in the gas stream for removal at a later step. The gas then is compressed further and passes through two absorbers in series to remove the carbon monoxide with a refrigerated copper ammonium formate solution and to remove the carbon dioxide

TABLE 1.—TYPICAL SYNTHESIS GAS ANALYSES AFTER CARBON MONOXIDE CONVERSION

Source (analysis)	Coke (vol. %)	Natural Gas (vol. %)
Hydrogen	51.0	60.0
Nitrogen	16.5	20.0
Carbon Dioxide	28.0	16.0
Carbon Monoxide	3.5	3.5
Methane + Argon	.5	.5
Hydrogen Sulfide	.5	.0
Total	100.0	100.0

W. W. Yeandle is now associated with Deere & Co., of Moline, Ill. From 1942 to 1951 he served Spencer Chemical Co., Pittsburg, Kan., for two years as superintendent, gas-reforming department, and thereafter as director, research and development. He is the author of "Methanol" section of the Encyclopedia of Chemical Technology and patentor of process for prilling ammonium nitrate and other salts. Mr. Yeandle was graduated from Yankton (So. Dak.) College, with a B.A. degree in physical sciences. His present title with Deere is manager of chemical division.

George F. Klein, Jr., chief engineer of the Spencer Chemical Co., Pittsburg, Kan., was graduated from the University of Missouri with a degree in chemical engineering. With Spencer he was first employed as a senior engineer in the engineering department in 1946, and in 1948, was made director of process development in the research and development department. Early in 1951, he was advanced to his present position as head of the engineering department. Prior to going to Spencer, he worked for Proctor and Gamble, Allied Chemical and Dye, and Hercules Powder Co.

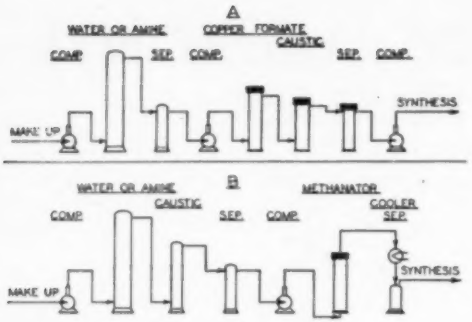

Fig. 1. Gas flow through typical purification systems.

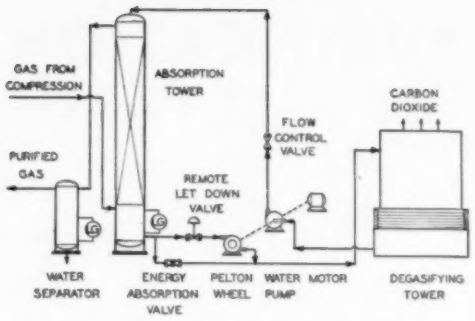

Fig. 2. Carbon dioxide removal with water absorption.

ide with a caustic solution. The purified gas is then compressed to final synthesis pressure, residual carbon oxides content being in the order of 25-50 p.p.m.

In Figure 1(B), generally typical of high-pressure syntheses, the synthesis gas is compressed first to 400-500 lb./sq. in. gage and passed through two absorbers in series for removal of carbon dioxide, the first absorber using water and the second a caustic solution. The gas stream then is compressed to final synthesis pressure and passed through a guard or "purifier" converter containing catalyst, with the residual carbon monoxide being converted with hydrogen to methane and water. The methane is an inert constituent and does not poison the catalyst, but it must be removed either by its dissolution in ammonia liquid product or by purge since its build-up in the synthesis cycle prohibitively reduces effective pressure of the reactants.

Carbon Dioxide Removal with Water

From a practical and economical standpoint, carbon dioxide cannot be removed from mixed gases at atmospheric pressure, and from a study of the absorption of carbon dioxide in water at various pressures and temperatures, it is readily apparent that absorption by water is not adequate below 200 lb./sq.in. gage.

The commonly employed means of carbon dioxide removal, namely, absorption in water, is illustrated in some detail in Figure 2; equipment comprises an absorption tower, a water-separator for the purified gases, a water circulating pump, a power-recovery turbine and energy-absorption valve, and a water-degasifying tower.

Imposing typical flow conditions on Figure 2, 5000 std.cu.ft./min. of reformed gas enters the absorber unit at 250-275 lb./sq.in. gage in counterflow to 4000 gal./min. of water which has been deaerated and cooled. Under average operating conditions, the gas leaving the absorber contains 0.5% to 0.8% residual carbon dioxide (removed at a subsequent process step). The water is recirculated in a closed system except for a modest make-up of evaporation and mechanical loss, and lends itself, therefore, to chemical treatment for corrosion and algae control. The water leaving the bottom of the absorber, almost saturated with carbon dioxide, can be let down and immediately directed over the degasifier tower; however, normal operation provides for recovery of energy from the water by directing it to an undershot Pelton power-recovery turbine gear and shaft connected to the pump serving the absorber. This reduces the load on the motor drive by approximately one third. A motor-driven valve regulates the flow of water from the absorber to the Pelton wheel while maintaining a seal in the bottom of the absorber. This valve can be operated either automatically from a level-control unit on the absorber or by a remote manual switch.

TABLE 2.—TYPICAL ANALYSES OF GAS RELEASED FROM WATER ABSORPTION OPERATIONS

Source (analysis)	Coke (vol. %)	Natural Gas (vol. %)
Hydrogen	6.0	31.0
Nitrogen	.0	8.5
Carbon Dioxide	92.3	58.5
Carbon Monoxide	1.5	2.0
Methane	.0	.0
Hydrogen Sulfide	.2	.0
Total	100.0	100.0

Equipment design is not unusual except that in some plants absorbers are as large as 8 ft. in diam. and are packed with Raschig rings. While it is exceptional that bubble trays are not used in a column of such cross-sectional area, it is to be noted that absorbent flow rate is uncommonly high, and no evident channeling is encountered.

The continuous degasification and cooling of the water absorbent operates without undue attention and requires little maintenance. Several modifications of the water-absorption system are practiced commercially as dictated by local requirements.

There are many modifications in the equipment used for degasifying the water from the water-absorption tower, some plants being designed to recover valuable constituents of the released gas. Besides carbon dioxide, considerable quantities of hydrogen and nitrogen as shown in Table 2 are released due to their substantial solubility in water at the pressures employed for this operation. The usual scheme for recovering the release gases is to pass the water to an intermediate release tank operating at 15 to 40 lb./sq.in. gage. In this vessel a major portion of the hydrogen may be recovered along with other gases. The release gas may have value only as a low B.t.u. fuel if plant design has not anticipated recycle.

Carbon Dioxide Removal with Alkylamines

The absorption of carbon dioxide in alkylamines, such as is typified in the Girbotol process, is not particularly restricted as to working pressure, although this process is accompanied by prohibitively high losses of the absorbent if attempted at atmospheric or low-pressure conditions. Most commercial plants employ pressures from 10 lb./sq.in. gage upward, and often at more than 200 lb./sq.in. gage, to reduce equipment size. In the case of the Jayhawk Works (Spencer Chemical Co.), where both alkylamine and water absorption are employed, the alkylamine absorption has replaced three originally installed water absorption units, primarily to furnish high purity carbon dioxide for dry ice and methanol processes. As a consequence, it is designed to operate at 250 lb./sq.in. gage in order to fit in with and utilize existing equipment.

A typical solution used to absorb the carbon dioxide is a 15-20% aqueous solution of monoethanolamine. One mole of alkylamine combining with one mole of carbon dioxide and water forms the amine carbonate, and can react further with a mole of carbon dioxide and water, to form the amine bicarbonate in the same way as do other alkaline solutions. Carbon dioxide

may be released then by heating, since the alkylamine loses its capacity for acid gas combination at moderately elevated temperatures. In actual practice, the amine solution is neither completely reacted to the bicarbonate in the absorption step, nor is it completely stripped down to the amine in the reactivation step. A typical dynamic operating condition is: 1.5 std.cu.ft. of carbon dioxide/gal. of lean 20% monoethanolamine solution from the reactivator and 6.0 std.cu.ft. of carbon dioxide/gal. of lean 20% monoethanolamine solution from the absorber, the net capacity then being 4.5 cu.ft./min. of carbon dioxide per gallon per minute of solution pumped.

The equipment required for amine absorption is shown schematically in Figure 3, consisting of an absorption tower, a reactivator tower, solution coolers, circulating pumps, separators for the purified gas and carbon dioxide gas streams, and an amine solution clean-up still. Should a high purity carbon dioxide be desired, some additional equipment is required since there is a minute amount of alkylamine residue in the regenerated carbon dioxide and if hydrogen sulfide has been a component of the gas purified, it will appear in the carbon dioxide stream from the regenerator.

Imposing typical flow conditions on Figure 3, 15,000 std.cu.ft./min. of synthesis gas enters the absorber at 250 lb./sq.in. gage in counterflow to 500 gal./min. of monoethanolamine solution which has been reactivated and cooled. The purified gas returns to further compression after passing through a separator for removal of entrained amine solution. The rich solution from the bottom of the tower flows through heat exchangers, being heated by the hot solution leaving the reactivator, and is let down through a valve to 40 lb./sq.in. gage for feed to the reactivator or stripping column. Steam to the reboiler of the reactivator strips out the carbon dioxide which is removed from the top of the column after passing a water condenser, a water cooler, and separator, with the condenser so designed as to reflux the column and maintain the water-content constant. The lean solution from the bottom of the reactivator flows first through heat exchangers, being cooled by the rich solution, and is let down to a solution surge tank. From this tank the lean solution is pumped through water coolers and then through a flow control valve to the absorber to complete the cycle.

Considerable information has been published concerning the operating and maintenance problems encountered in amine absorption systems. Generally, however, operation can be maintained quite easily by the proper control of temperatures, pressures and solution purity, giving a residual synthesis gas leaving the absorber of 0.2 to 0.5% carbon dioxide content. During continued operation, there is some deterioration of the amine solution together with vapor losses from the absorber which must be replaced. Solution purity and pH are maintained by removing a side stream of the lean solution from the system and passing it through a small vacuum still unit, often with addition of caustic, removing the bottoms product from the system and returning the overhead to the solution surge tank.

Carbon Monoxide Removal with Copper Ammonium Formate

Removal of carbon monoxide from gas streams by absorption with a copper ammonium formate solution involves a number of chemical reactions the mechanisms of which are not definitely established and therefore, will be discussed on the basis of empirical data. In the absorption step a complex molecule of carbon monoxide and cuprous ammonium formate is formed, which upon heating is dissociated and releases the carbon monoxide. This complex molecule is 100% associated at −2° C. and 760 mm. partial pressure of carbon monoxide when four moles or more of free ammonia per mole of cuprous ion are present. Under ideal conditions, one mole of cuprous ammonium formate, lactate, acetate, carbonate, etc., will absorb one mole of carbon monoxide for each equivalent of cuprous ion in solution. On a plant scale this somewhat theoretical figure is never attainable, with practical experience showing that 70% of the theoretical capacity may be realized provided the liquor is kept at 0 to 5° C., and the molecular balance maintained correctly.

The major equipment for this operation is shown in Figure 4, consisting of a gas-absorption tower, a solution-regeneration vessel, a caustic absorber, gas separator, and solution coolers and circulating pumps. Not shown but also required is the equipment for preparing the cuprous ammonium formate and caustic solution.

Imposing on Figure 4 typical conditions, 4000 std.cu.ft./min. of gas enters the first absorber at 1800 lb./sq.in. gage in counterflow to 75 gal./min. of cuprous ammonium formate solution which has been cooled to +5° C. From this absorber the gas stream is directed to, and passes upward through, a second absorber in counterflow with a circulated caustic or aqua ammonia solution. The gas then flows through a separator and is returned for further compression, the total carbon oxide content generally being less than 25 p.p.m.

The copper solution leaving the bottom of the absorbing tower passes directly to the top of a trifunctional tower as shown in Figure 4 which serves to regenerate the rich liquor by (1) dissociation of the molecular complex and expulsion of the dissolved gases with heat, (2) controlled oxidation of the cuprous ion, and (3) make-up and recovery of ammonia.

The rich solution entering the top of the regeneration tower passes down through the packed reflux section where a large portion of the carbon monoxide is liberated from the liquor and released to the atmosphere, the cool solution acting to reabsorb the ammonia released from a subsequent heating step. The solution then flows through an outside line to the heated bottom section where the liquor is intermediately accumulated. Air is admitted into the bottom section in the proper quantity to oxidize some cuprous ion to cupric, the ideal ratio being approximately 1:5 to insure that no metallic copper will be precipitated from solution in the absorber. Ammonia is added also to the solution to make up for losses sustained at various points in the system.

The liquid head against the bottom reservoir induces a steady flow of solution upward through the calandria tubes in the center or regenerator section. Overflowing the tubes, the liquor has reached such a temperature level that carbon monoxide and ammonia are released and with some nitrogen pass upward through the top section packing meeting the downflowing cold solution from the absorber. The stripped liquor passes then downward and thence upward through an annular section concentric to the calandria bundle and finally over a weir and through coolers, completing the cycle. Figure 5 shows in some detail the design of the reactivator.

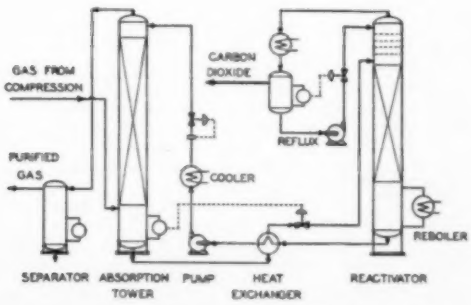

Fig. 3. Carbon dioxide removal with amine absorption.

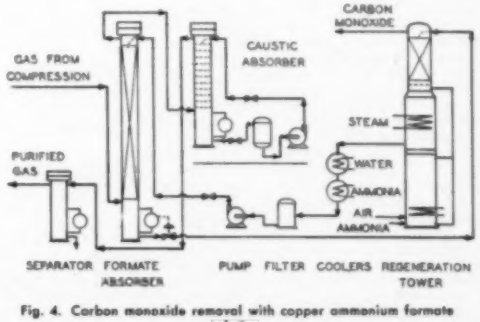

Fig. 4. Carbon monoxide removal with copper ammonium formate solution.

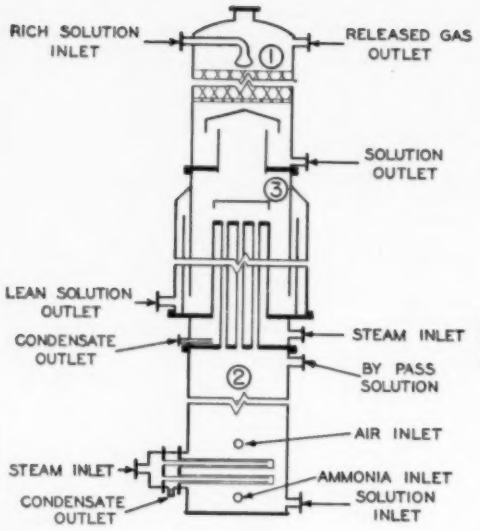

Fig. 5. Copper ammonium formate solution regeneration tower diagram.

Carbon Monoxide Removal by Methanation

The removal of residual carbon monoxide by catalytic conversion with hydrogen to methane and water is practiced in most of the plants operating at high synthesis pressures, that is, 12,000 to 15,000 lb./sq.in. gage. This type of purification is not commonly used in low-pressure synthesis plants, probably due to the high purge imposed by high methane in the synthesis cycle. There is, of course, some loss of compressed hydrogen in this system; however, this loss is offset by the simplicity and economy of operation if the carbon monoxide has been reduced to low concentration in the water-gas shift units.

The methanation step is generally carried out at synthesis pressure in a reactor which may be identical or similar in design to the ammonia converters. The reactor, or guard converter, is loaded with catalyst which may be the same as that used for ammonia synthesis, although lower activity catalyst can be used; as a matter of fact, spent synthesis catalyst is often employed. The reactor is designed with internal heat exchange and an arrangement for a by-pass around the heat exchanger such that temperature control of the strong exothermic reaction can be maintained in the range 400-450° C. Immediately downstream of the methanation reactor there is provided a cooler-condenser and liquid separator for removal of the rather heterogeneous condensate mixture of water, methyl alcohol, methylamine, etc. It may be well to observe that ammonia synthesis catalyst will not tolerate substantial amounts of water vapor in the nitrogen-hydrogen mixture and it is equally important to remove both water vapor and the carbon oxides.

The comparative economics of carbon monoxide removal by the methanation vs. removal by copper ammonium formate are complex, but certainly costs are not greatly different. The methanation system requires less plant investment and saves the cost of pumping and refrigeration which are inherent in the copper liquor system. As against this, the solution absorption system does not introduce inert constituents into the synthesis, thereby conserving expensive compressed reactant gases. No fair comparison can be made since neither system would be satisfactory if substituted for the other, each having been developed for its particular conditions of operation.

Removal by Liquid Nitrogen Wash

Carbon Monoxide, Methane, Argon, and Acetylene. A unique and efficient process for removing non-reactants and poisonous constituents from hydrogen, while simultaneously supplying a substantial proportion of the nitrogen required for ammonia synthesis, is employed in some plants. It is used in one instance in conjunction with a true hydrocarbon gas cracking wherein elemental carbon is produced as a by-product.

TABLE 3.—TYPICAL ANALYSES OF SYNTHESIS GAS IN COPPER AMMONIUM FORMATE UNIT NATURAL GAS PLANT

Source (analysis)	Feed Gas (vol. %)	Vent Gas (vol. %)
Hydrogen	71.0	4.0
Nitrogen	23.4	8.0
Carbon Dioxide	1.0	30.0
Carbon Monoxide	4.0	55.0
Methane + Inerts	.6	3.0
Total	100.0	100.0

The hydrogen gas is directed through an absorber-type packed or plate column under several atmospheres pressure in contact with liquid nitrogen of high purity from an auxiliary air liquefaction plant. Under controlled conditions, the carbon monoxide, methane and argon are liquefied and purged from the bottom of the column with some remaining nitrogen liquid, while the hydrogen together with evaporated nitrogen pass out the top, essentially free of undesirable constituents. Nitrogen gas is added at a downstream point in the system to maintain proper H_2/N_2 ratio for ammonia synthesis. The low content of inerts in this synthesis gas allows good catalyst life and gives high conversion to ammonia.

Use of this purification scheme in conjunction with alternate methods of hydrogen production has been proposed but cannot be disclosed at this time.

Discussion

James De Lury (J. F. Pritchard & Co., Kansas City, Mo.): Since you have had experience in the removal of carbon dioxide both by water scrubbing and amine treating, could you give us some comparative economics on those two processes?

W. W. Yeandle: That's a controversial point. In our own plant we went to the amine type from the water-scrubber type because of the need for pure CO_2 both for dry ice and methanol manufacture. However, if a plant is properly set up on the basis of the Girbotol process and utilizes waste heat, which is normally lost, the economics may be equal to or possibly better than water scrubbing. In our own experience, we find perhaps a small advantage in water scrubbing costwise, but we find a compensating advantage processwise in using the Girbotol method when pure CO_2 is required for other operations.

John J. Dorsey, Jr. (Commercial Solvents Corp.): The same comment may apply to your experience with the low-pressure formate solution. Would you care to dwell a little more on the comparison of CO removal in low-pressure and high-pressure systems?

W. W. Yeandle: We find no particular penalty in operating at either pressure level. The cost of pumping is a little less at the low pressure.

Max F. Mueller (J. T. Baker Chemical Co., Phillipsburg, N. J.): At what pressure does your water scrubber for CO_2 removal operate?

W. W. Yeandle: Our removal at Jayhawk is set at 250 lb.-gage and at our other operation at 400-lb. gage. Either one is satisfactory.

(Presented at A.I.Ch.E. Kansas City (Mo.) Meeting.)

HIGH-PRESSURE HYDROGENATION OF CRUDE SHALE OIL

M. G. PELIPETZ, M. L. WOLFSON, H. GINSBERG, and E. L. CLARK

Bureau of Mines, Bruceton, Pennsylvania

Crude shale oil, obtained by the retorting of Colorado oil shale in a gas-flow retort, was hydrogenated over several solid catalysts in a continuous high-pressure unit on a once-through basis. At 9000 lb./sq.in. gage hydrogen pressure and at temperatures of 800° to 900° F., a product oil essentially free of sulfur and nitrogen and suitable for further processing by standard petroleum methods can be produced. Using tungsten or cobalt molybdate catalysts, 40 to 50 vol. % of the product oil obtained by hydrogenation can be utilized as high-quality diesel fuel (cetane ratings of 50 to 60). Depending on the type of catalyst used and the temperature of operation, hydrogen consumption varied from 2000 to 2800 cu.ft./bbl. of shale-oil feed.

DURING the past three decades, the amount of energy derived from coal has remained practically the same while the energy produced through consumption of oil and natural gas has increased fivefold (*9*). This large increase in oil and natural-gas demand was met through the expansion of the petroleum industry. In spite of these efforts the United States has become a net importer of oil since 1948 (*6*). The investigation of additional domestic sources of liquid fuels is, therefore, a necessary safeguard to our future economy, which continues to demand ever-increasing supplies of liquid and gaseous fuels.

Oil shale appears to be the most promising of the prospective materials suitable for the production of synthetic liquid fuel. Preliminary calculations indicate that specified fuels production from shale oil can be achieved considerably more economically than from coal. Oil shale is found in 20 states and Alaska, but the Green River formation of Colorado, Utah, and Wyoming is considered the most important known deposit. It has been estimated that from a 1,000-sq.-mi. area of the oil-shale deposits of Western Colorado approximately 300 billion bbl. of crude shale oil can be recovered (*9*).

Crude shale oil, as obtained by thermal retorting of oil shale, is a high-gravity somewhat asphaltic oil containing approximately 2% nitrogen and about 0.7% sulfur. Without additional refining, crude shale oil meets the specifications for a residual fuel only. Previous investigations with Colorado shale oil have indicated considerable improvement in oil quality by hydrogenation of both shale-oil-coker distillate at 1500 lb./sq.in. pressure (*2*) and crude shale

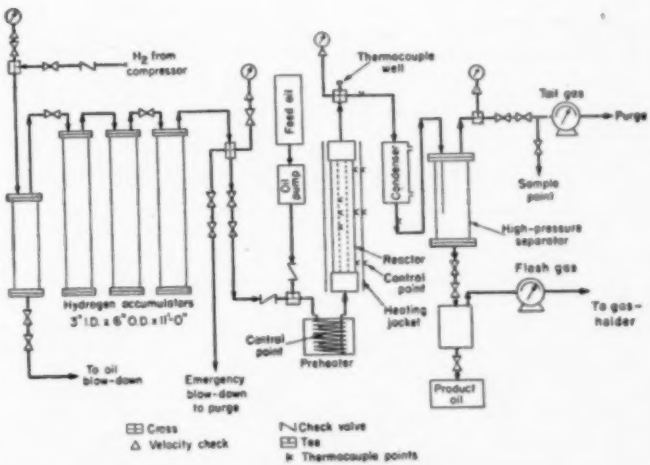

Fig. 1. Flow diagram.

Additional tabulations, containing 16 pages, are on file (Document 3624) with the American Documentation Institute, 1719 N Street Northwest, Washington 6, D. C. Obtainable by remitting $1.00 for microfilm and $2.40 for photoprints.

oil at 3000 to 4000 lb./sq.in. pressure (*4, 8*).

The purpose of this study was to investigate the conversion of crude shale oil by high-pressure hydrogenation at 9000 lb./sq.in. pressure over a solid catalyst to more valuable liquid fuels or to a material suitable for further processing by petroleum refining methods. This conversion requires a sufficient reduction in nitrogen content to permit the use of commercial cracking catalysts which are adversely affected by basic nitrogen compounds (*5*).

Experimental Method

Crude shale oil was hydrogenated in a bench-scale continuous unit. No recycling was done in any of the tests. A self-explanatory flow diagram of the unit is shown in Figure 1. The design and operation of this unit have been described in detail in a previous paper (*10*). The catalyst charge in all the tests was 100 cu.cm. of 6- to 8-mesh granules prepared by crushing and sieving the pelleted catalysts. Four catalysts were used, and several tests were conducted with each catalyst charge. The results reported represent the averages of the pertinent tests. All tests except tests 8 and 9 over tungsten sulfide catalyst (Table 2) were made at 9000 lb./sq.in. pressure. Following German practice, a hydrogen flow rate of 10.5 cu.ft. (measured at standard conditions)/100 g. of oil feed was maintained in all the runs.

TABLE 1.—INSPECTIONS OF CRUDE SHALE-OIL FEED

Specific gravity 60/60°F	0.9167
A.P.I. gravity	22.1
Pour point, °F	95
Viscosity, S.U., sec.	
at 130°F	345
at 210°F	81
Ultimate analysis, wt.-%	
nitrogen	2.87
sulfur	0.67
hydrogen	11.16
carbon	84.86
Conradson carbon, %	6.22
Flash C.O.C.	295°F
ASTM sed., %	0.05
Moisture, %	0.05
Benzene insoluble, wt. %	0.01
Benzene insoluble, wt. %	4.40
ASTM distillation, temp., °F at	
Initial boiling point	425
5%	496
10%	514
20%	552
30%	606
40%	646
50%	667
60%	681
70%	695
Recovery, 71%	667

	Bureau of Mines distillation: Observed pressure, mm.Hg	End point temp., °F, corrected to 760 mm.Hg	Vol.-%	Sp. Gr., 60/60°F.
Naphtha	760	392	1.56	0.835
Light distillate	40	590	13.13	0.866
Heavy distillate	40	804	44.16	0.911
Residue	40		37.52	1.025
Loss			2.63	

TABLE 2.—HYDROGENATION OF CRUDE SHALE OIL—100 CU.CM. TUNGSTEN SULFIDE CATALYST, PRESSURE 9,000 LB./SQ.IN. GAGE

Test No.	1	2	3	4	5	6	7	8[a]	9[a]
Temperature, °F, average	750	750	790	825	825	825	825	825	825
Space Velocity, gm. Feed/c.c. cat./hr.	1.0	0.5	0.5	0.5	1.0	1.5	0.5	0.5	1.0
Duration of Test, hrs.	48	48	72	96	120	48	166	144	120
Hydrogen Consumption, Ft.³/bbl.	1400	1600	2140	2590	2210	1800	2660	1900	1330
Hydrocarbon Gas Production, Ft.³/bbl.	80	85	155	250	215	125	245	250	155
Liquid Product									
Wt. % of Feed	96.8	96.7	95.4	93.4	94.2	95.8	93.2	93.3	95.5
Vol. % of Feed	101.7	101.65	105.7	110.0	106.5	104.3	107.6	106.8	102.6
Specific Gravity	0.861	0.874	0.853	0.803	0.836	0.866	0.820	0.842	0.8
Ultimate Analysis, Wt. %									
Nitrogen	0.43	0.32	0.02	0.03	0.03	0.27	0.09	0.38	0.9
Sulfur	0.13	0.08	0.06	0.03	0.03	0.07	0.05	0.09	0.1
Hydrogen	13.08	13.23	13.70	14.49	13.94	13.48	14.27	13.43	12.7
Carbon	86.05	86.08	86.85	85.45	85.54	86.04	85.62	85.70	85.6
Atom Ratio H/C	1.82	1.84	1.94	2.03	1.96	1.88	2.00	1.88	1.7
Gasoline Production (0-392°F), Vol. % Feed	1.7	2.1	6.1	24.3	16.4	10.2	15.6	14.6	10.8
Diesel Fuel Production (392-660°F) Vol. % Feed	38.5	37.5	43.75	55.3	48.2	43.9	53.0	46.9	40.1

[a] These tests run at 4,000 p.s.i.g.

TABLE 3.—HYDROGENATION OF CRUDE SHALE OIL—100 CU.CM. TUNGSTEN-NICKEL SULFIDE CATALYST, PRESSURE 9,000 LB./SQ.IN. GAGE

Test No.	1	2	3	4	5
Temperature, °F	840	840	840	797	840
Space velocity, gm. feed/c.c. cat./hr.	1.5	1.0	1.0	1.0	1.5
Duration of test, hrs.	72	48	72	48	72
Hydrogen consumption, Ft.³/bbl.	1900	1720	2070	1620	1710
Hydrocarbon gas production, Ft.³/bbl.	215	250	295	160	135
Liquid product					
Wt. % feed	93.7	92.9	91.4	96.2	95.6
Vol. % feed	105.9	103.9	104.0	103.3	108.0
Specific gravity	.837	.845	.831	.862	.837
Ultimate analysis, wt. %					
Nitrogen	0.10	0.28	0.05	0.44	0.27
Sulfur	0.04	0.04	0.03	0.05	0.05
Hydrogen	13.72	13.49	13.88	13.39	13.55
Carbon	85.44	85.30	85.63	86.00	85.61
Atom ratio H/C	1.93	1.89	1.95	1.87	1.90
Gasoline production (0-392°F), vol. % feed	16.7	14.3	19.4	9.8	
Diesel-fuel production (392-660°F) vol. % feed	47.4	46.6	49.7	40.4	

Feed Stock. The feed stock was a filtered shale oil produced in a pilot plant gas-flow retort at the Bureau of Mines oil-shale demonstration plant at Rifle, Colo. The characteristics of the feed are summarized in Table 1. According to Bureau of Mines distillation data, the charging stock contained about 14 vol. % of light distillate (392° to 592° F.) and less than 2 vol. % of 392° F. E.P. gasoline. The 18° A.P.I. gravity, high Conradson carbon of 6.2%, and almost 5% asphaltene (*n*-hexane insoluble) content indicate that this crude oil would be difficult to refine. The 2% nitrogen content must be reduced before either a suitable synthetic petroleum crude or specification products can be produced.

Catalysts. Four catalysts were tested:

Tungsten sulfide,* I. G. Farben catalyst No. 5058, composed of 100% tungsten sulfide; obtained from German stocks in 10- by 10-mm. cylindrical pellets.

Tungsten and nickel sulfide,* I. G. Farben catalyst No. 8376, composed of 27% tungsten and 8% nickel impregnated on alumina as sulfides; obtained from German stocks in 10- by 10-mm. cylindrical pellets.

Cobalt molybdate on alumina, prepared according to the method of Byrnes *et al.* (*1*); supplied by the Union Oil Company as 6- by 6-mm. cylinders. This catalyst had been investigated at lower hydrogen pressures for shale-oil-coker distillate (*3*) and crude shale oil (*5*).

Molybdenum, zinc, and chromium oxides on acid-treated diatomaceous earth, Ruhroel catalyst No. K-536. The analysis and typical operating characteristics of this catalyst have been reported previously (*10*).

To reduce to sulfides any sulfite or sulfates formed during the long storage period, catalysts containing tungsten (5058 and 8376) were heated at 400° C. for 30 hr. in a stream of hydrogen plus hydrogen sulfide (about $20H_2$: $1H_2S$) flowing at a rate of about 0.4 cu.ft. gas/(hr.)(125 cu.cm. of catalyst).

Tungsten Sulfide. The first catalyst used was tungsten sulfide (Table 2). For coal-hydrogenation oils the temperature range of operation recommended for this catalyst is 750° to 790° F. After several preliminary tests on shale oil it was found that at temperatures above 790° F. the rate of nitrogen elimination was increased. At 825° F. and a space velocity of 1.0 g. of oil/hr. (cu.cm. of catalyst), almost complete nitrogen and sulfur removal was effected, and approximately 65 vol. % of the liquid product boiled below 660° F. Liquid volume recovery under these conditions was over 100%, and the hydrogen consumption was 2210 cu.ft./bbl. of feed. This catalyst appeared to be quite durable even though the temperature of operation was higher than that normally used. Thus, test 7, after 432 hr. of catalyst operation, gave results similar to those obtained in test 4, which was made after 168 hr. of catalyst operation. Dropping the pressure from 9,000 lb./sq.in. gage to 4,000 lb./sq.in. gage lowered the rates of nitrogen elimination and of reduction of molecular weight (compare tests 4 and 5 with tests 8 and 9).

Tungsten Nickel Sulfides. Four tests (Table 3) with supported tungsten nickel sulfides catalyst were made at 840° F. and one at 797° F. At a temperature of 840° F. and space velocity of 1.0 the elimination of

* Additional information on preparation and operation with these I. G. Farben catalysts is available (*3* and *7*).

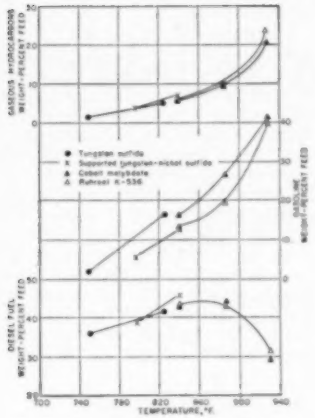

Fig. 2. Hydrogenation of crude shale oil, 9,000 lb./sq.in. gage, space velocity 1.0.

nitrogen was found satisfactory, while at a temperature of 797° F. about 0.5% of nitrogen was found in the product oil. In general, the rate of nitrogen elimination was lower than that obtained with tungsten sulfide, although the comparison was complicated by the unequal operating temperatures. Comparison of tests 1 and 5, both under similar conditions but at different catalyst age (test 1 was the initial test; test 5 was run after 240 hr. of operation), indicates some loss of hydrogenation and cracking activity.

Cobalt Molybdate. The cobalt molybdate catalyst was prepared for intermittent operating with air regeneration, and therefore had good temperature stability. Operating temperatures were 840°, 887°, and 930° F. to increase the gasoline fraction in the product. At 930° F. and a space ve-

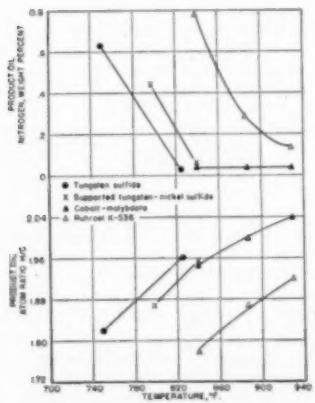

Fig. 3. Hydrogenation of crude shale oil, 9,000 lb./sq.in. gage, space velocity 1.0.

TABLE 4.—HYDROGENATION OF CRUDE SHALE OIL—100 CU.CM. COBALT MOLYBDATE CATALYST, PRESSURE 9,000 LB./SQ.IN. GAGE

Test No.	1	2	3	4
Temperature, °F	840	887	930	840
Space velocity, gm. feed/c.c. cat./hr.	1.0	1.0	1.0	1.5
Duration of test, hrs.	72	96	48	48
Hydrogen consumption, ft.³/bbl.	2130	2390	2820	1530
Hydrocarbon gas production, ft.³/bbl.	345	400	670	300
Liquid product				
Wt. % feed	92.2	98.8	76.0	93.2
Vol. % feed	105.5	109.9	95.9	106.0
Specific gravity	.887	.816	.769	.832
Ultimate analysis, wt. %				
Nitrogen	0.04	0.04	0.04	0.08
Sulfur	0.03	0.01	0.00	0.02
Hydrogen	13.99	14.27	14.49	13.68
Carbon	85.94	85.65	85.35	86.07
Atom ratio H/C	1.953	1.999	2.037	1.907
Gasoline production (396°F., E.P.) vol. %	20.7	33.6	52.7	15.2
Diesel-fuel production (396-660°F) vol. %	48.2	49.7	33.6	47.6

TABLE 5.—HYDROGENATION OF CRUDE SHALE OIL—100 CU.CM. RUHROEL K-536 CATALYST, PRESSURE 9,000 LB./SQ.IN. GAGE

	1	2	3	4	5	6	7
Temperature, °F	840	840	887	887	887	930	930
Space velocity, gm. feed/c.c. cat./hr.	1.0	0.5	1.0	0.5	1.5	1.0	1.5
Duration of test, hr.	48	96	48	96	72	48	48
Hydrogen consumption, ft.³/bbl.	1300	1865	2800	2300	1680	2810	2740
Hydrocarbon gas production, ft.³/bbl.	255	345	590	485	330	1005	795
Liquid product							
Wt. % feed	93.0	89.6	86.7	84.1	89.6	75.0	79.2
Vol. % feed	102.2	102.5	99.9	100.5	101.3	91.6	93.7
Specific gravity	0.871	0.837	0.831	0.804	0.847	0.784	0.809
Ultimate analysis, wt. %							
Nitrogen	0.19	0.15	0.29	0.13	0.67	0.14	0.29
Sulfur	0.07	0.03	0.04	0.03	0.06	0.03	0.05
Hydrogen	12.65	13.37	13.43	13.85	13.00	13.79	13.49
Carbon	85.78	86.13	85.99	85.92	86.15	86.04	86.17
Atom ratio H/C	1.765	1.862	1.873	1.932	1.820	1.921	1.877
Gasoline production (396°F E.P.), vol. %	16.6	19.6	24.2	32.5	21.5	49.7	35.0
Diesel fuel production (396-660°F) vol. %	47.6	49.5	47.8	43.9	49.3	31.1	46.0

TABLE 6.—DIESEL FUEL FRACTION—SHALE-OIL HYDROGENATION PRODUCT

Catalyst	Tungsten Sulfide		Supported Tungsten Nickel Sulfide	Cobalt Molybdate	Ruhroel K-536		
Temperature, °F, average	825	825	840	840	840	887	930
Space Velocity gm./c.c., cat./hr.	0.5	1.0	1.5	1.5	1.0	1.0	1.0
Specific gravity	.839	.836	.841	.843	.852	.849	.843
Bromine No.	1.3	3.3	1.5	1.1	27.8	19.6	0.1
Aniline pt., °F	180	178	169	160	135	114	139
Flash point, °F	188	186	188	188	--	--	--
Viscosity SSU at 100°F	35.6	36.6	39.0	37.7	32.1	35.2	34.0
at 210°F	29.1	29.6	32.3	31.5	30.8	29.3	29.8
Pour point, °F	+12	+12	3	12	9	3	-7
Cetane No.	53.2	56.0	52.9	60.6	40.8	46.8	46.6
Sulfur, Wt. %	0.03	0.02	0.02	0.01	0.07	0.06	0.02
Nitrogen, Wt. %	0.03	0.03	0.10	0.05	0.78	0.33	0.15
Atom Ratio, H/C	2.00	1.94	1.92	1.89	1.80	1.82	1.79
ASTM Dist., °F at							
IBP	422	432	418	418	410	435	417
30	482	486	503	502	498	482	462
50	506	511	523	530	525	509	483
70	548	548	560	563	556	544	521
E.P.	606	606	615	620	604	612	615

TABLE 7.—GASOLINE FRACTION

Catalyst	Tungsten Sulfide	Supported Tungsten-Nickel Sulfide	Cobalt Molybdate on Alumina			Ruhroel K-536	
Temperature, °F, average	825	840	840	887	930	887	930
Space velocity, gm. feed/c.c. cat./hr.	0.5	1.0	1.0	1.0	1.0	0.5	1.0
Specific gravity	.7804	.780	.782	.780	.748	.763	.758
Bromine number	1.81	0.13	5.4	5.9	5.8	9.9	10.5
Oct. no., cc./100 c.c.	38.0	38.4	43.1	0.1	7.4	20.2	19.8
Octane No. F.3. clear	38.0	58.6	60.1	59.1	58.4	47.3	51.7
Nitrogen, wt. %	.02	0.06	0.01	0.01	0.00	0.10	0.08
Sulfur, wt. %	.03	.03	.03	.04	.03	.04	.02
ASTM Dist., °F at							
IBP	235	183	174	176	163	177	151
10	257	248	217	219	216	208	207
30	293	284	275	279	297	268	282
50	317	310	306	300	295	293	279
70	335	335	334	330	314	327	306
90	359	353	365	361	357	357	348
E.P.	383	401	410	400	407	392	387

locity of 1.0, more than 50 vol. % of the product boiled in the gasoline range. Rates of nitrogen and sulfur elimination were satisfactory, but hydrocarbon-gas production and hydrogen consumption were high.

Ruhroel K-536. Table 5 presents the data obtained with Ruhroel K-536 catalyst. In Germany this catalyst was used at 930° F. for the conversion to gasoline of gas oils obtained by pitch hydrogenation. The tests with crude shale oil were made at 840°, 887°, and 930° F. The rate of nitrogen and sulfur removal and of reduction in molecular weight increased with increasing temperatures. Both the nitrogen removal and cracking rates on this catalyst, however, were inferior to those on cobalt molybdate, as shown, for example, by comparison of test 6 in Table 5 with test 3 in Table 4.

Experimental Results

To indicate the relative efficiency of the catalysts used, the results at a space velocity of 1.0 and at varying temperatures were compared. In Figure 2, the weight per cent of feed stock converted to gaseous hydrocarbons, gasoline, and diesel fuel was plotted against temperature. In Figure 3 the nitrogen content of the product in weight per cent and the atom ratios of hydrogen to carbon for the product oils were plotted against temperature.

Figure 2 indicates that the temperature coefficient of the rate of reduction in molecular weight and the selectivity of the cracking (*i.e.*, relative amounts of diesel oil, gasoline, and hydrocarbon gases) are approximately the same for all of the four catalysts. When the temperature of operation was increased above 840° F., production of gasoline and gaseous hydrocarbons increased at the expense of diesel fuel. The original feed stock contained approximately 1.5 vol. % of gasoline and 30 vol. % of diesel fuel.

In Figure 3 the weight per cent of nitrogen in the liquid product and the hydrogen-to-carbon atom ratio of this product are plotted against the temperature for each catalyst. Data obtained with three of the catalysts could be represented satisfactorily by one curve, which however would not fit the data obtained with Ruhroel K-536 catalyst. The hydrogen-to-carbon atom ratio of the product may be considered a measure of the hydrogenation activity of the catalysts. Tungsten, tungsten nickel, and cobalt molybdate are active in hydrogenation of crude shale oil, while catalyst K-536 has good cracking activity but little saturation activity.

The product oil in several of the tests was distilled, and the fraction boiling between 396° and 660° F. was examined to estimate its suitability as diesel fuel. The results are listed in Table 6. It appears that a high-quality diesel fuel can be obtained directly, without further processing, by the use of tungsten sulfide, tungsten nickel sulfide, or cobalt molybdate catalysts. The tungsten sulfide catalyst produces the best diesel fuel, an oil of low pour point as well as high cetane number. The dilute molybdenum, zinc, and chromium catalyst on fuller's earth (K-536) produces a poorer quality diesel fuel, which, however, is suitable for low-speed engines. As the temperature of operation for this catalyst is increased, the olefin content of the diesel fuel decreases, as is evident from the lowered bromine number. At operating temperatures of 930° F., the decreased pour point and decreased hydrogen-to-carbon atom ratio may be considered as evidence of some increase in aromaticity.

The gasoline fractions (boiling below 396° F.) of several of the product oils were separated and examined (*see* Table 7). In general, the octane ratings of the gasolines are below the standards for motor gasolines. The Ruhroel K-536 catalyst seems best for gasoline production, but some additional processing would be necessary to obtain a suitable octane number. On the basis of the gum values, the cobalt molybdate catalyst produces the most stable gasolines.

Comment and Conclusions

Before any conclusions can be drawn from the data, their accuracy must be defined. Values for liquid products given in Tables 2 to 5 include only the material actually condensed by water cooling in the hydrogenation plant. The gaseous hydrocarbon yield includes butanes and some heavier hydrocarbons. As a result, the gasoline fraction, which was obtained by distillation of the liquid product actually condensed to 396° F., represents a conservative estimate of the potential gasoline production. The omission of the light hydrocarbons from the gasoline fraction would also result in a somewhat lower octane rating.

In general, to obtain a product of low nitrogen content by hydrogenation of crude shale oil, an active hydrogenation catalyst and an operating temperature of 825° F. were necessary. It did not appear feasible to produce large amounts of high-quality gasoline directly from crude shale oil by a one-step hydrogenation. A high-quality diesel fuel was prepared by the use of several catalysts. Recycling all material boiling above the diesel-fuel range may make a complete conversion to diesel fuel and gasoline possible, but the economic feasibility of this recycle process depends on the disposal of low-grade gasoline representing approximately 25- to 35-vol. % of the total product. For example, the data obtained with tungsten sulfide catalyst at 9,000 lb./sq.in. gage, 825° F., and 1.0 space velocity indicate a ratio of 3 vol. of diesel fuel to 1 vol. of gasoline in the liquid product.

The preparation of suitable raw material, or synthetic crude, for subsequent processing by conventional petroleum-refining methods seemed quite feasible. Data obtained with tungsten sulfide, tungsten nickel sulfide, and cobalt molybdate show a high recovery of oil with a low nitrogen and sulfur content. The hydrogenation conditions can be adjusted so that the liquid product contains a minimum of gasoline, a relatively large volume of diesel fuel, and a residue sufficiently low in nitrogen content to permit the use of standard cracking catalysts. Hydrogen consumption for this type of product would be less than 2300 cu.ft./bbl. of feed.

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PRESSURE DROP FOR HIGH VACUUM FLOW OF AIR

Through Annular Sections

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The isothermal flow of air at room temperature through four commercially smooth horizontal concentric copper annuli, O.D. of 3 in., has been studied by measurement of the pressure differentials and the flow rates. In the transition region between molecular flow and viscous flow, the flow is found to be the sum of the viscous and molecular flow contributions (Eq. (5)). Use of the theoretically derived molecular flow correction, K, for annuli of Barrett and Bosanquet (2) leads to a large variation with geometry of f, the fraction of the molecules diffusely reflected. Alternately, use of a constant f equal to the circular pipe value results in a value of K of nearly 1.0 to within the limit of experimental error. No variation of f with flow rate was found.

INDUSTRIAL processes operating at high pressures have been common for a generation, but it has been only during the last several years that very low pressures have come into extensive use. Extremely low pressures are used in the various atomic research instruments (cyclotrons, etc.). Pressures of a few microns are employed in the manufacture of electronic equipment, the production of magnesium metal from dolomite, drying of antibiotics and of blood plasma, concentration of vitamins, and the coating of lenses. Moderately low pressures find use in the concentration of fruit juices and other food products. The necessary vacuum is obtained by the use of mechanical pumps, multistage jets, and large oil-condensation pumps.

No matter how good the vacuum at the pumps, it is evident that the pressure in the process equipment itself may be unnecessarily high and even excessive if the piping and connections are not designed to handle the gas flow with an economically small pressure drop due to friction. Ideally, the duct used should be short and large for vacuum flow, but circumstances in installation and practice often dictate shapes and lengths other than this simple ideal.

The case of flow through circular cross sections has been successfully treated by theory and the results confirmed by experiment. Barrett and Bosanquet (*2*) recently developed expressions by which it should be possible to calculate the flow or pressure drop in molecular flow through annular sections. There are, however, at the present time no experimental data on vacuum flow through annuli. It is, then, the purpose of this research to investigate the applicability of the present theory, to extend this to the region of slip flow, to check experimentally these equations, and to make available actual experimental data for vacuum flow through annular sections.

Theory

As a result of his investigation of gas flow at very low pressures, Knudsen (*10*), assuming wholly diffuse reflection and no velocity gradient normal to the walls as well as postulating Maxwellian distribution, derived his "free molecule" flow equation for circular pipes

$$Q = \frac{4}{3}\sqrt{\frac{2\pi RTg_o}{M}}\,\frac{r^3}{L}\,(p_1 - p_2) \tag{1}$$

where Q is the mass flow in pressure volume units.

By qualitative reasoning Knudsen extended his equation to other shapes by replacing L/r^3 by

$$\frac{\pi}{2}\int_0^L \frac{O}{A^2}\,dL \tag{2}$$

where O is the wetted perimeter and A is the cross-sectional area. Smoluchowski (*14*) generalized the equation for the case where only a fraction f of the molecules are diffusely reflected. The final modified Knudsen equation for any uniform section is

$$Q = \frac{8}{3}\sqrt{\frac{2RTg_o}{\pi M}}\,\frac{A^2}{OL}\left(\frac{2}{f} - 1\right)(p_1 - p_2) \tag{3}$$

Cheng (*5*) derived the above equation and obtained a constant smaller by $3\pi/16$ than that given above and hence identical with the molecular flow part of the slip flow equation (*3, 9*); however, as Cheng did not use the proper value for the average velocity and momentum, his equation is inadmissible. Experimentally, Brown et al (*4*) found no minimum in the mass flow per unit pressure drop between molecular flow and viscous flow for copper pipe as had been observed by Knudsen and Gaede for glass capillaries (*8*). Data of Brown et al, however, were not at a high enough vacuum to be conclusive. The effect is probably caused by different tube materials.

Annular Cross-section Conduit. Although Equation (3) may be used as an approximation, a careful analysis indicates that the equation is not exact even for pure molecular flow. The more rigorous deductions of Lorentz (*13*) allow accurate equations for the flow through an element of area for any cross-sectional shape to be obtained, but the integrals left standing in the final expression for the complete cross-sectional flow cause his relation to be unsuitable for practical purposes. Bosanquet (*2*) developed a relation which, while similar to that of Lorentz, was easier to evaluate. This allowed Barrett and Bosanquet (*3*) to determine a correction factor, K, for the right-hand side of Equation (3). This equation then becomes, for the annular section,

$$Q = \frac{8}{3}\sqrt{\frac{\pi RTg_o}{2M}}\,\frac{K}{L}\,\frac{(a^2 - b^2)^2}{(a+b)}\left(\frac{2}{f} - 1\right)(p_1 - p_2) \tag{4}$$

* Present address: Union Oil Company of California, Oleum, Calif.

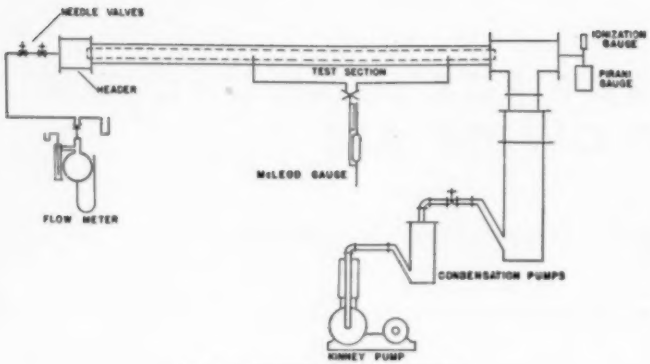

Fig. 1. Diagrammatic sketch of apparatus.

Values of K as determined by Barrett and Bosanquet are given in Table 1 and in Figure 7.

The present authors will postulate as several authors have done that for the intermediate region between viscous and molecular flow the total flow can be calculated as the sum of the viscous and molecular flow contributions. Alancraig (*2*) gives the derivation for the slip flow equation for an annulus. However, as the equation cannot apply as molecular flow is approached and it is rather complex, it is not presented. For flow through the annular section one has, using Poiseulle's law (*11*) for the viscous flow contribution,

$$Q = \frac{\pi g_c Z^4}{16\eta L}(p_1^2 - p_2^2) + \frac{8}{3}\sqrt{\frac{\pi RTg_c}{2M}}\frac{K}{L}\frac{(a^2-b^2)^2}{(a+b)}\left(\frac{2}{f}-1\right)(p_1-p_2) \quad (5)$$

or for p in microns of mercury, η in centipoises, T in °K. and all linear dimensions in centimeters, Q in liter microns of mercury per second becomes (*7*)

$$Q = \frac{0.0262Z^4}{\eta L}(p_1^2 - p_2^2) + 30.5\sqrt{\frac{T}{M}}\frac{K}{L}\frac{(a^2-b^2)^2}{(a+b)}\left(\frac{2}{f}-1\right)(p_1-p_2) \quad (5a)$$

where

$$Z^4 = a^4 - b^4 - \frac{(a^2-b^2)^2}{ln\frac{a}{b}} \quad (6)$$

TABLE 1.—VALUES OF CORRECTION FACTOR K FOR ANNULAR SHAPES

Calculated by Barrett and Bosanquet (*3*)

Radius ratio b/a	K_{bb}
0	1.000
0.259	1.073
0.500	1.154
0.707	1.254
0.866	1.430
0.966	1.675

It will be more convenient when comparing data with theory to use the Knudson No., $\lambda/2r$, or similar quantity as one parameter to evaluate possible changes in f with flow rate.

For this the mean free path λ will be used as calculated from viscosity as follows:

$$\eta = 0.499\rho\bar{c}'\lambda = \rho\left(\frac{2RTg_c}{\pi M}\right)^{1/2}\lambda = p\lambda\frac{2Mg_c}{\pi RT} \quad (7)$$

If one multiplies and divides the right-hand term in Equation (5) by η and its equivalent in order to insert λ into the equation, letting λ be evaluated at

$$\frac{p_1+p_2}{2} = p,$$

after simplification one obtains:

$$Q = \frac{\pi g_c}{16}\frac{p_1^2-p_2^2}{\eta L}\left[Z^4 + \frac{64}{3\pi}K\frac{(a^2-b^2)^2}{a+b}\left(\frac{2}{f}-1\right)\lambda\right] \quad (8)$$

This may be rewritten

$$(F-1) = \frac{64}{3\pi}\left(\frac{2}{f}-1\right)\frac{\lambda}{X} \quad (9)$$

where

$$F = \frac{16Q\eta L}{\pi g_c(p_1^2-p_2^2)Z^4} \quad (10)$$

and

$$X = \frac{(a+b)Z^4}{(a^2-b^2)^2K} \quad (11)$$

Note that for circular pipes $Z = X = r$. Thus, a plot of $(F-1)$ vs. λ/X on log-log paper should have a slope of unity if f is a true constant and independent of flow rate. From any particular value on the curve it is possible to calculate the value of f.

Description of Apparatus

The experimental apparatus is a horizontal annular section connected to a source of vacuum through which a measured quantity of carefully dried room air flowed under steady and essentially isothermal conditions. Figure 1 is a schematic drawing of the apparatus.

Source of Vacuum. The primary source of vacuum is a Distillation Products, Inc., type metal oil-diffusion pump, which has a manufacturer's rated speed of 500 l./sec. at $1/10\mu$. A DPI metal oil-diffusion pump, rated at 200 l./sec. at 1μ, is used as the booster pump. Octoil was used in both condensation pumps. The roughing pump is a Kinney Manufacturing Co. model. A DPI combination high-vacuum valve and baffle, placed between the vacuum pumps and the rest of the system, allowed the pumps to operate continuously while the test section was being changed. A standard 6-in. glass-pipe tee is mounted above the baffle valve. One end of the cross is connected to the monitoring gages; the other end, to the test section.

Test Section. The annulus consists of an upstream calming section, 4 ft. long, a 5-ft. test section, and a one and a half-foot downstream calming section. The distance between the pressure taps is 5.005 ft. The annulus is constructed of standard 16 BWG copper tubing. O.D. tubing of 3 in. is used for the outside tube; the core diameter was varied in half-inch steps from 2½ in. to 1 in. Each end of the core is supported by three cap screws spaced at 120° intervals on the periphery of a 5-in. diam. brass collar. To provide additional support to the core, quarter-inch long rods of proper thickness and spaced at 120° intervals around the core are soldered to the core, 3½ ft. in from each supporting collar. The core is sealed at the upstream end by a flat copper plate, but the downstream end is open.

The Header. Since the outlet of the needle valves is a brass tube ¼-in. I.D., it was believed that some device was needed to assure an even flow into the annulus. A fritted glass disc of 60-mm. diam., the largest ultra-fine porosity disc available, was used for this purpose. The upstream calming section also aided in assuring even flow through the test section.

Needle Valves. Two vacuum needle valves in series were used in order to obtain smooth and easy control of the flow rate.

Flow Meter. The flow-rate-measuring device was constructed and used according to the design of Alexander (*1*). Its use is described in detail by Alancraig (*2*). P_0 is measured on the manometer connected to the flask and simultaneously the pressure, p, in the vacuum system is measured. The stopcock is then rotated through 360°, so

TABLE 2.—RUN I

$L = 152.6$ cm. $r = 3.640$ cm.

Q $l-\mu$/sec.	p_1 μ	p_2 μ
0.695	0.0413	0.0144
3.49	0.208	0.0666
8.17	0.498	0.151
42.5	2.56	0.632
85.4	3.95	1.63
144	6.30	2.71
589	16.2	7.01

that the flask is restored to atmospheric pressure momentarily and then reconnected to the vacuum system. The time required for the mercury in the manometer arm connected to the flask to fall from the initial pressure, P_1, to some final pressure, P_2, is measured with a stop watch. Since the ratio of P_1/P_2 was kept less than 1.05, the pumping speed can be considered constant. The flow rate, Q, is then

$$Q = VP_2(\ln P_1/P_2)/t \qquad (12)$$

A cathetometer capable of being read to one-twentieth of a millimeter was used to measure the difference in height of the liquid in the manometer.

TABLE 3.—RUN II

$L = 152.6$ cm. $a = 3.640$ cm.

$b = 1.269$ cm. $K_{33} = 1.08$

Q $l-\mu$/sec.	p_1 μ	p_2 μ
2.13	0.169	0.0563
2.36	0.203	0.0575
2.63	0.300	0.0773
5.17	0.491	0.158
8.59	0.888	0.248
16.1	1.51	0.426
30.1	3.17	0.834
62.0	5.88	2.25
84.0	7.216	2.57
28.7	8.50	7.22
179	13.2	4.70
55.9	14.5	12.2
119	24.3	20.5
184	34.2	29.1
164	58.4	57.1
420	66.8	60.4

Gages

1. *Monitoring.* An ionization gage and a Pirani gage were connected into the system at the glass tee in order to allow instantaneous pressure changes to be detected. Both gages were used for monitoring purposes only. The control circuits for the gages were manufactured by Distillation Products, Inc.

2. *Measuring.* A multiple-range McLeod gage was used to measure the pressure drop. The gage has a range of 0.004 to 300μ Hg in four stages and was constructed according to the design appearing in Dunoyer-Smith (6). All readings were made by determining the height of mercury necessary to compress the gas to a given volume. A two-way stopcock was used to connect the gage into first the one-pressure tap, then the other.

The original multiple-range McLeod gage was inaccurately calibrated in the two highest-pressure ranges. The gage was then replaced by a McLeod gage whose 3-mm. diam. capillary was precision bore tubing and whose bulb had a volume of 700 cc. Readings were made on this gage by determining the height of mercury necessary to compress the gas to one of two given volumes. The gage thus had a range of 0.1 to 300μ Hg.

Experimental Procedure

After each exposure of the system to atmospheric pressure, the system was allowed to pump down under no-flow conditions. A 36-hr. pump-down period was used since no provision had been made to heat the test section to facilitate out-gassing.

A preliminary run, using the outer pipe without a core, was made. The purpose of this run was to test for constant error in the apparatus by checking the flow data against the accepted relations for circular cross sections and to determine the value of Maxwell's coefficient f for the copper being used. Several points were taken in both the slip and free molecule flow regions.

For each annular section used, the flow rate was varied over as wide a range as possible with the available pumps and McLeod gages. After each adjustment of the flow rate, at least half an hour was allowed for the system to come to dynamic equilibrium. All pressure drop and flow-rate measurements were repeated several times as a check.

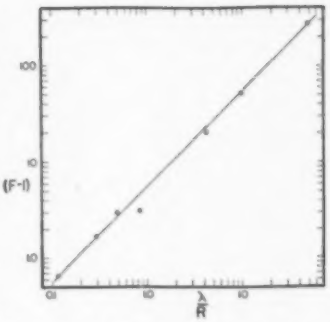

Fig. 2. Graph of Equation (9) for circular cross-section.

Experimental Data

Tables 2-6 summarize the experimental data. More complete data and calculations are recorded (2). All data were taken at $22 \pm 4°$ C.

Results

A graph of the calculated values $F-1$ vs. λ/X for each run is presented in Figures 2-6. It will be noted that in all cases the experimental data lie near a straight line with a slope of unity. This indicates that f is independent of the Knudsen number, or ratio of mean free path to characteristic dimension. The data cover a range so that the molecular flow contribution varies from 99% to 50%. The least squares slope m using the proper weighting procedure (2) for each run was determined and the values are tabulated in Table 7.

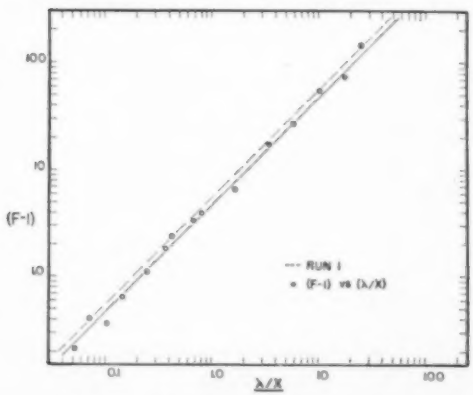

Fig. 3. Graph of Equation (9) for annular cross-section, $b/a = 0.3485$.

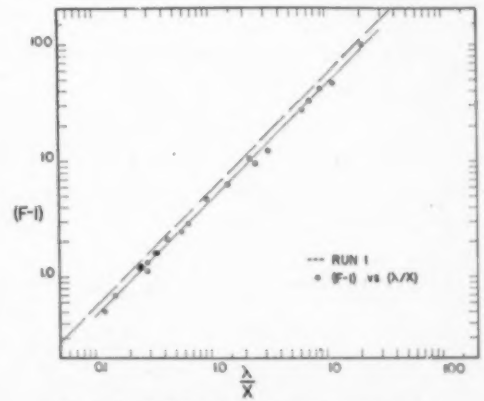

Fig. 4. Graph of Equation (9) for annular cross-section, $b/a = 0.5233$.

TABLE 4.—RUN III

$L = 152.6$ cm. $a = 3.640$ cm.

$b = 1.905$ cm. $K_{bb} = 1.17$

Q l — μ/sec.	p_1 μ	p_2 μ
2.31	0.366	0.105
3.91	0.686	0.163
5.94	0.888	0.210
7.04	1.09	0.270
7.94	1.27	0.319
14.1	2.47	0.619
19.1	3.20	0.754
25.2	3.55	0.942
34.9	5.33	1.69
61.3	8.02	2.68
84.8	11.5	3.78
103	13.3	4.12
154	17.2	5.73
195	21.2	6.99
220	22.4	7.10
243	25.4	9.16
238	26.1	8.70
304	29.3	10.9
308	29.1	10.3
592	46.9	18.3
228	45.0	34.8

It will be noted that the best slope in every case is very close to unity. Because of obvious errors, Point 1, Run 1 and Points 10, 12, 13, and 14, Run IV, were not used in the least squares calculation.

The value of 1.10 for f found for circular copper pipe agrees almost exactly with the value given by Cheng (*4, 5*) for copper pipe after correcting for his incorrect constant.

By imposing a slope of unity and using the theoretically determined values of Barrett and Bosanquet for K, the values of f listed in Table 7 were calculated. It may be noted that the values of f are greater than unity. It is not inconceivable that f should exceed unity in value, indicating that the molecules are reflected on the average with a partial reversal of their tangential velocities. However, one would usually expect f to lie below unity. In any case f may be considered simply an adjustable parameter.

Since f is presumed to depend upon the character of the interaction between the gas molecules and the surface, though it may vary with temperature, one would at first expect in the case of the annulus that the value of f would be constant regardless of the geometry. However, it could be anticipated that the value of f might increase as the annulus is progressively narrowed, since then an increasing amount of surface area is available for small angles of incidence. This last trend was actually observed, the value of f for the smallest annulus being nearly 15% greater than the value of f for the circular cross section. The variation of f with (b/a) is shown in Figure 8 and Table 7.

Millikan (*13*) determined values of f for several gas-surface combinations by two different methods involving radically different geometries and obtained excellent agreement. Thus, whereas Millikan's work indicates that f is not a function of geometry, data here indicate that it is, if Barrett and Bosanquet's values of K, i.e., K_{bb}, are accepted.

By assuming a constant value for f of 1.10 which was its value in the circular pipe, values of K called K_e were calculated. Values of K_e should apply in Equation (5) if f were a true constant. These are also listed in Table 7 and Figure 7.

A careful study of the Barrett and Bosanquet paper showed that their theoretical development could not be ruled out on grounds of unreliability or lack of rigor. A calculation (*2*) from their equation for K_{bb} checked well with their published values for K.

Example. In a certain high-vacuum molecular still a cold trap is to be inserted between the pump and the evacuated equipment to remove easily condensable materials. The trap which is to be connected to the pump mouth is to consist of an annular section of 4 in. × 8 in. std copper pipe cooled to −73° C. It is expected from past experience that 150 l. μ of air/sec. at S.T.P. will be continually liberated from the equipment which is to be maintained at a pressure of 1μ. The conductance of the necessary pipe including end effects and bends has been calculated by equations summarized in Dushman (*7*) to be 700 l./sec. at 20° C. The speed of the pump between 0.1 and 1μ is 500 l./sec. What is the maximum length of annular section which may be used?

Pressure at pump mouth = $150/500 = 0.3\mu$. = p_2

Pressure at annular section entrance = $1 - 150/700 = 0.786\mu = p_1$

$Q = 150 \times 200/273$ 1μ/sec.

$\eta = 1.34 \times 10^{-4}$ poises $= 1.34 \times 10^{-5}$ cps.

Take $K = 1.0$; $f = 1.1$ (will change some as material condenses)

$a = 10.2$ cm. $b = 5.7$ cm.

$T = 200°$ K. $M = 29$

We substitute into Equation (5), (5a) or (8) and solve for L.

$L = 103$ cm. $= 3.4$ ft.

A 3-ft. section should probably be used to be conservative.

The molecular flow contribution in this case is 94 cm. which clearly indicates that this type of flow is predominate.

TABLE 5.—RUN IV

$L = 152.6$ cm. $a = 3.640$ cm.

$b = 2.537$ cm. $K_{bb} = 1.25$

Q l — μ/sec.	p_1 μ	p_2 μ
1.73	0.606	0.150
4.72	1.86	0.417
10.9	4.31	1.22
20.5	6.18	1.94
32.1	9.05	2.79
60.8	17.2	5.27
99.9	24.1	6.41
128	31.3	9.16
156	36.0	11.2
175	37.6	12.6
220	46.9	16.5
340	58.1	21.3
545	78.7	32.1
621	95.6	48.7

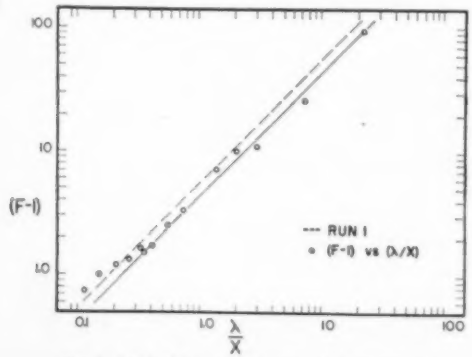

Fig. 5. Graph of Equation (9) for annular cross-section, $b/a = 0.6968$.

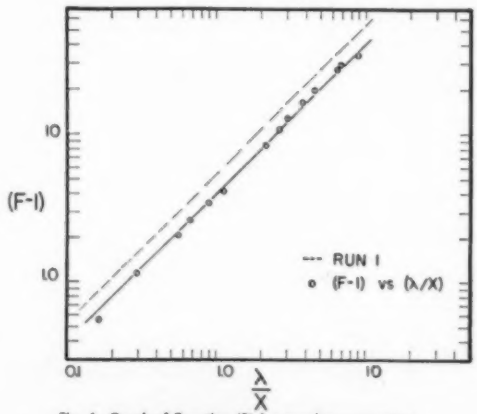

Fig. 6. Graph of Equation (9) for annular cross-section, $b/a = 0.8719$.

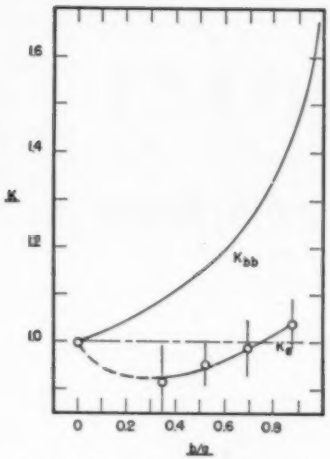

Fig. 7. Plot of theoretical and experimental values of K against b/a.

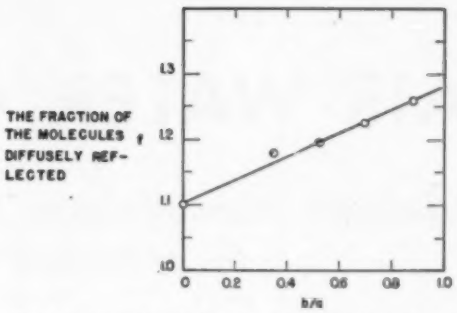

Fig. 8. Variation of f with the radius ratio for annular sections.

Conclusions

Equation (5), which expresses the total flow as the sum of viscous and molecular flow contributions, together with the values of K from Barrett and Bosanquet (*2*) and the experimental f's from Table 7 or Figure 8, may be used to calculate accurately the vacuum flow of air or pressure drop through annular copper sections. The equation should also be applicable to other systems if f may be estimated. However, further work should be done to establish clearly the relationships for other systems. If one uses the straight pipe value of f and K is taken as unity, the equation will fit the data within experimental error. This latter result is merely fortuitous and without sound theoretical basis.

The quantity f was found to be independent of the rate of flow.

Notation

A = area available for flow, sq.cm.

a = radius of outer pipe of annulus, cm.

b = radius of core of annulus, cm.

$F = (16)\ QnL/\pi g_c(p_1^2 - p_2^2)\ Z^4$

f = fraction of molecules diffusely reflected

g_c = gravitational constant conversion factor, (1.332×10^{-3}) (liter) (poise)/(cc.) (micron of mercury) (sec.)

K = annulus correction factor for Equation (4), (5), or (8)

K_{bb}, K_e = Barrett and Bosanquet, and experimental (using constant f) values, respectively, of K

L = length of section, cm.

M = molecular weight

m = least squares slope of line

O = perimeter, cm.

P_1, P_2, P_3 = initial, final, and running pressures, respectively, in flow meter, microns of mercury

p_1, p_2 = upstream and downstream pressures, respectively, microns of mercury

Q = mass rate of flow, (liter) (microns of mercury)/(sec.)

R = universal gas constant $(6.236 \times 10^4$ liter microns/° K. g. mole) = pipe radius in Fig. 2

r = radius of pipe, cm.

T = absolute temperature, ° K.

t = time, sec.

V = volume, liters

v' = average molecular velocity

$X = (a+b)(Z^4)/(a^2-b^2)^2\ (K)$, cm.

$(Z^4) = ((a^4-b^4)-(a^2-b^2)^2/\ln a/b)$, cm.^{4}

η = coefficient of viscosity, poises (centipoises in Equation (5a))

λ = mean free path, cm.

μ = micron of mercury = 10^{-3} mm. Hg

TABLE 6.—RUN V

$L = 152.6$ cm. $\quad a = 3.040$

$b = 3.174$ cm. $\quad K_{bb} = 1.44$

Q $l-\mu$/sec.	p_1 μ	p_2 μ
2.02	3.85	1.38
2.34	4.42	1.46
3.69	5.65	1.46
5.77	7.33	2.71
6.45	9.51	2.63
6.40	11.1	4.31
8.91	13.6	3.64
8.91	15.7	5.72
22.4	32.5	8.18
23.4	37.5	14.3
40.2	52.1	15.9
40.0	55.9	23.3
99.1	112	45.1
212	196	84.9

TABLE 7.—SUMMARY OF CALCULATED DATA

Run	Radius ratio b/a	Slope m	f	K_e (assuming $f = 1.10$)
I	0	0.99	1.10	1.00
II	0.3485	1.02	1.18	0.92 ± 0.07
III	0.5233	0.99	1.20	0.96 ± 0.04
IV	0.6968	0.97	1.23	0.99 ± 0.06
V	0.8710	1.02	1.26	1.04 ± 0.05

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AIR-WATER CONTACT

Adiabatic Humidification of Air with Water In a Packed Tower

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MANY industrial processes are in some manner concerned with the transfer of energy and mass between two fluid phases in intimate contact. In order to employ the basic two-film theory, data are required concerning the resistances of the individual films. Unfortunately such information is extremely meager in the published literature. Some data representing measured over-all coefficients are available but it is not practical to separate the individual resistances primarily because the functions involved are complex and the data available are not sufficiently accurate.

Thus, the ultimate objective of experimental research in this field is the development of complete correlations of the heat- and mass-transfer coefficients of the individual phases over wide ranges of system dimensions, operating variables, and the physical properties of fluids.

To eliminate completely the resistance of one phase, the temperatures and concentrations at the interface must be identical to those in the main body of this phase over the tower. The liquid-film resistance can be eliminated by the evaporation of a pure liquid into an insoluble gas and adjusting the inlet liquid temperature equal to the exit. Absorption of a very soluble gas, e.g., ammonia in water, is unsatisfactory as careful experiments (*1, 4*) show the presence of an appreciable liquid-film resistance. The gas-film resistance can be eliminated by the isothermal condensation of a pure vapor into a nonvolatile liquid. However, the usual procedure of absorption of a very insoluble gas, e.g., H_2, O_2, or N_2, is much simpler and apparently the gas-phase resistance is negligible (*10, 11, 13*).

Scope of Present Work. The present investigation was undertaken to obtain accurate individual heat- and mass-transfer coefficients for the gas film over wide ranges of operating variables for the single system air-water. Information of this kind would then provide the starting point for the desired general correlation just discussed.

The liquid-film resistance to mass transfer was eliminated by the evaporation of water, saturated with air, into the air stream and to heat transfer by adjusting the inlet water temperature until identical to the exit water temperature.

To extend the scope of previous investigations, wide ranges of flow rates were employed: 120 to 6800 lb./(hr.)(sq.ft.) for the liquid and 100 to 1900 lb./(hr.)(sq.ft.) for the gas. The maximum air flow represents approximately loading conditions above which it was impossible to remove all entrained water from the exit air sample. The inlet air temperature was varied from 100 to 260° F. in order to obtain reasonable driving forces. Three heights (3⅛, 6$\frac{5}{8}$ and 13⅛ in.) of 1½-in. Berl saddles were investigated and a large tower (21.5 in. on a side) was used to eliminate wall effects, corner effects, etc.

Pertinent Literature. At the start of this investigation the only published data representing individual gas-film coefficients in a packed tower were a set of measurements by Johnstone and Singh (*8*) on 1-in. Raschig rings at $L = 1000$ lb./(hr.)(sq.ft.) and $G = 523$ to 2410 lb./(hr.)(sq.ft.) for which $h_G a_H a (G)^{0.95}$. Later, McAdams and co-workers (*9*) reported the results of an investigation of 1-in. Raschig rings in a 4-in. diam. tower over a restricted range of air flow and liquid flow [$G = 350$ to 1000 lb./(hr.)(sq.ft.) and $L = 500$ to 2500 lb./(hr.)(sq.ft.)] for 6, 9, and 12 in. of packing.

The following relationship was presented:

$$(h_G a_H)_{70°F.} = 2.1 G^{0.70} L^{0.07}$$

These exponents, which varied but slightly with the other flow rate, are considerably different in absolute value from exponents reported here and are different from values predicted from analysis of much of the work on ammonia absorption which indicates that the exponents cover a wide range depending on the values of L, G, and Z. The low ratio of tower to packing diameter of 4:1 may have introduced "wall effects" into the determination. It should be noted that these liquid rates are generally in the transition region indicated in this study (Fig. 6) in which the exponent of the liquid rate is indeed low, particularly at low-gas rates.

The preceding two studies are the only ones for which individual gas-film data are reported. However, while it is not expected that the effect of L, G, and Z on over-all coefficients would be the same as for the gas film alone, it would be expected that the same general trends would be observed particularly if the gas film were controlling. Inspection of the data of Dwyer and Dodge (*1*), Fellinger (*4*) and others on the absorption of ammonia in water and Parekh (*12*) on humidification, all representing over-all coefficients, indicates the same general trends as determined in this study; i.e., the exponent of the gas rate varies considerably with L and Z

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Table 1 in its entirety is on file (Document 3618) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting $1.00 for microfilm and $1.00 for photocopies.

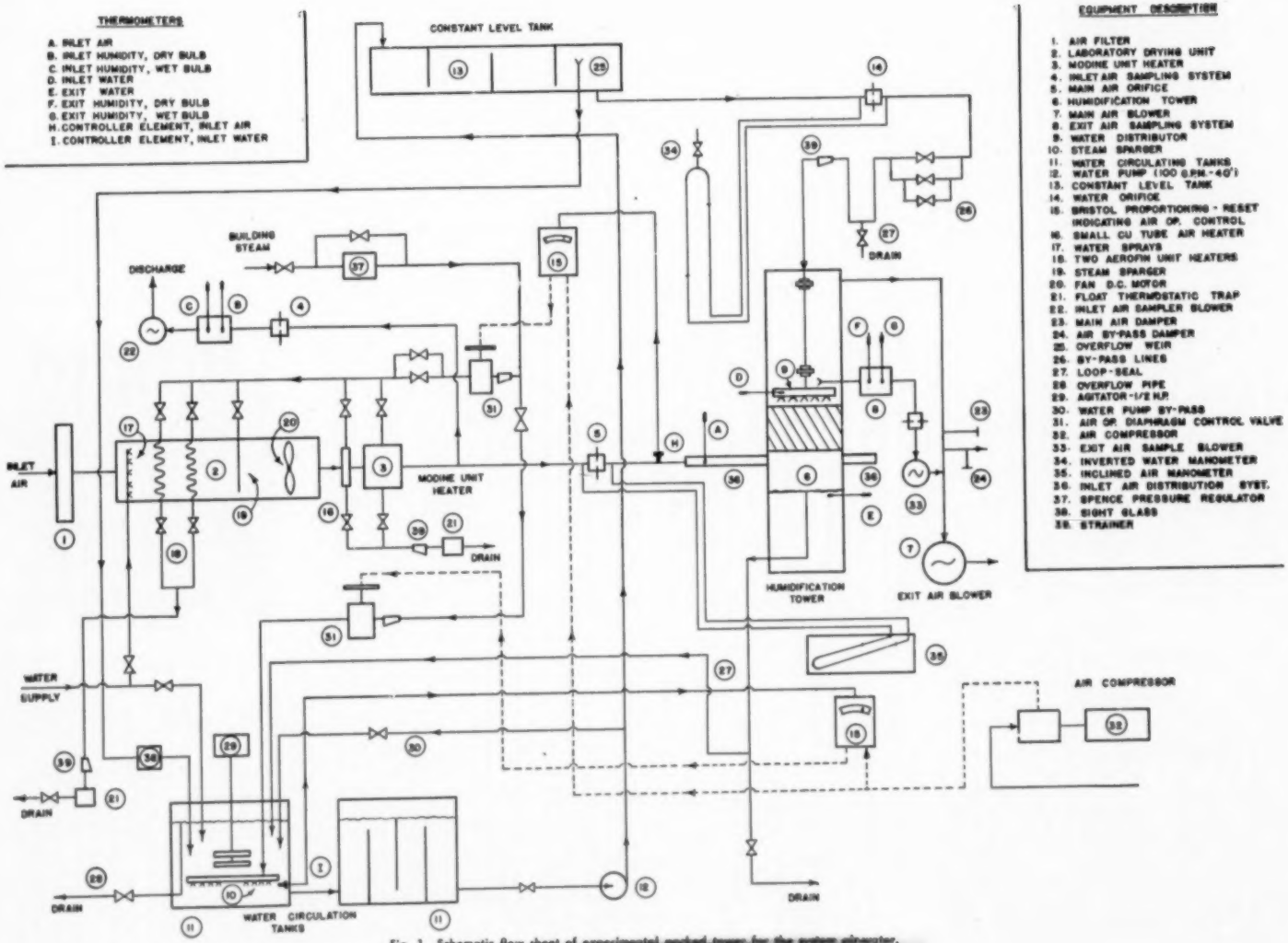

Fig. 1. Schematic flow sheet of experimental packed tower for the system air-water.

(Parekh (12) gives 0.43 to 0.64), that of the liquid rate varies somewhat with G and Z, and in most cases the exponents on the gas rate are lower and those on the liquid rate higher than reported by McAdams, et al (9). Data of Fujita (6), which actually represent over-all coefficients since the water temperature was not constant, indicate a gas rate exponent of approximately 1.2. However, a term in the correlation, $(V_W)^{0.5}$ – wet void, probably is also a function of the flow rates and this value of 1.2 probably does not represent the complete effect.

Thus, because of the lack of data and the contradictions in those data that are available, much work is yet to be done in this field.

Theoretical Analysis

Basic Equations. Elimination of liquid-film resistances to heat and mass transfer by the device used in this study leads to the following equations relating height of packed depth to the film coefficients for the gas phase:

$$h_G a_H = \frac{G(c_s)_{av.}}{Z} \ln \frac{t_{G_1} - t_L}{t_{G_2} - t_L} \tag{1}$$

$$k_G a_M = \frac{G}{Z} \ln \frac{H_L - H_{G_1}}{H_L - H_{G_2}} \tag{2}$$

The following assumptions are involved in the integration of the basic differential equations which led to the above:

1. Both the heat- and mass-transfer coefficients are constant over the height, Z, independent of temperature and humidity changes. Actually coefficients calculated from experimental data give an average value at some integrated average temperature and humidity in the tower.
2. The specific heat is considered constant at an average value.
3. In expressing partial pressures and vapor pressures in terms of humidity, Dalton's law is employed and it is considered that $P - p_i = P - p_G = p_{BM}$.
4. The water temperature is considered constant and the interface value equal to the main body temperature.

Correction Factors. In attempting to cover a wide range of the variables, L, G, and Z, the average film temperature and humidity were necessarily varied considerably. This required that the measured coefficients be corrected to the same average conditions before making correlations. An average gas-film temperature of 110° F. and a humidity of 0.015 lb./lb. were selected as standard values and all coefficients were corrected to these conditions by means of the following relationships:

a. In heat transfer, the experimental correlation of McAdams et al. (9) was employed.

$$h_G a_H = C \cdot e^{b \cdot \text{conv} t_f} \tag{3}$$

b. In mass transfer, the Chilton-Colburn mass-transfer-heat-transfer analogy was employed in the absence of specific experimental data.

$$k_G = \frac{h_G P}{c_s \rho_{BM} M_W \left(\frac{M_W}{M_A} + H\right)_f \left(\frac{c_s \rho D_v}{k_{th}}\right)_f^{2/3}} \tag{4}$$

Humidity Determination. Both inlet and exit humidities were measured by the wet-bulb technique, using the standard wet-bulb equation:

$$h_G a (t_G - t_{Wb}) = \lambda_{Wb} k_G (H_{Wb} - H_G) \tag{5}$$

For this purpose the extensive data of Dropkin (2) were analyzed and extrapolated to zero wet-bulb depression. The psychrometric ratio for the system air-water was taken to be (7)

$$\frac{h_G}{k_G} = 0.2355 \pm 0.0006$$

for $t_f = 47.7°$ F. and $H_f = 0.00702$ lb./lb. at an average air velocity of 1750 ft./min. Values of this ratio at other conditions were calculated by means of Equation (4) and radiation corrections were made using the method of Dropkin (3) after his data had been analyzed for observed emissivities (7).

Equipment and Procedure Details. A schematic flowsheet of the apparatus is presented in Figure 1. An 8-ft. high square tower (21.5 in. on a side) was employed and was insulated with 8 in. of Fiberglas semi-board. To secure uniform velocity of air entering the packing, the air was introduced into the four sides of the tower through 6-in. by 19-in. openings by a sheet metal distributor divided into four streamline channels by baffles and equipped with dampers. To reduce end effects, the packing support consisted of a ½-in. mesh wire grid supported by ¼-in. pipe at 5-in. intervals and was placed 4 in. above the center of the air inlet openings. The extremely efficient water distributor employed (Fig. 2) had 400 points of discharge, resulting in a coverage of 1.13 sq.in. of tower area an opening. This is compared with coverage of 4 to 12 sq.in. an opening achieved by previous investigations. The openings were of 1/16-in. and 1/32-in. diam. for the high- and low-range distributors respectively and were positioned ¾ in. above the surface of the packing.

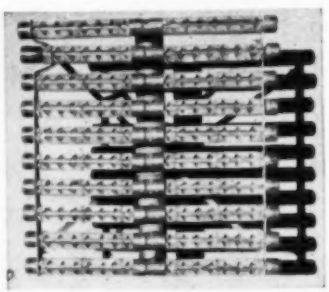

Fig. 2. Liquid distributor.

Air System. Filtered air was drawn through sprays and heaters downstream of which a 40-cu.ft./min. sample was removed continuously for measurement of temperature and humidity by standardized precision thermometers graduated to 0.05° F. (At high inlet air temperatures standardized thermometers graduated to 0.1° F. were employed.) It was not practical to control inlet humidity, and tests were made over a sufficient interval to average out atmospheric fluctuations. Radiation corrections to the wet bulb were kept to 1–2% by maintaining a mass velocity of 2–4 lb./(sec.)(sq.ft.) past the wet bulb. The dry bulb was carefully shielded. The main air stream was metered by orifices constructed to A.S.M.E. (5) specifications. The inlet air temperature was measured by standardized thermometers (shielded for radiation) inserted into the air duct just below the downstream orifice calming section and controlled by Bristol proportioning-reset controllers. The inlet air distribution system (covered with 4–6 in. of Fiberglas) had a large surface area and at the high air temperatures and low flow rates there was an appreciable heat loss. (Internal leakage of cold air contributed to the observed drop in temperature.) This system was calibrated at different air flows and static pressures in the tower to give the true average temperature of air entering the tower.

Directly above the water distributor a 40 cu.ft./min. sample of the exit air was removed continuously. The temperature and humidity were measured with standardized precision thermometers graduated to 0.05° F. A mass velocity of 2–4 lb./(sec.)(sq.ft.) was employed and the dry bulb was provided with a radiation shield and a shield which prevented any entrained water from impinging on the dry bulb but which permitted adequate circulation of the air sample around the thermometer.

Elaborate precautions were taken to reduce the amount of entrainment present in the exit air sample to an absolute minimum and to obtain a truly representative sample, since entrainment not only affects the wet- and dry-bulb readings directly but increases the "end effects." In the design finally adopted, no entrainment at the point of humidity measurement could be detected by chemical test at mass velocities, G, in the tower below 1800–1900 lb./(hr.)(sq.ft.), and the average path from the top of the packing to the thermometers was approximately 20 in. corresponding to an average of one-second passage time. The humid air was withdrawn from the top of the tower through a coarse screen by the main air blower and discharged to the atmosphere.

Water System. City water was heated by open steam sparging and pumped to a constant level tank from which it flowed by gravity through an orifice inserted in a 3-in. standard line and thus to the water distributor. The temperature of the water leaving the heating tanks was automatically controlled to ±0.1–0.2° F. and because of designed system time lag was constant to ±0.01–0.03° F. at the distributor. One of the arms of the distributor was brought out through the side of the tower and the temperature of the inlet water measured at this point by standardized thermometers (0.05° F. graduations). The exit water

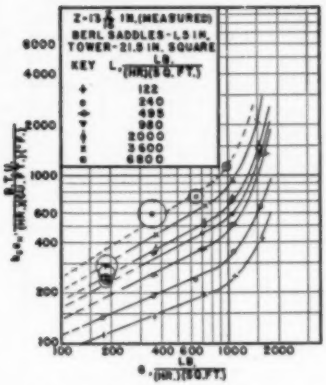

Fig. 3. Gas film heat-transfer coefficients, $h_G a_H$ vs. gas rate, G.

precision thermometer was inserted into the pool of water in the bottom of the tower beside the overflow pipe and ½ in. below the surface of the water.

Experimental Procedure. To measure only gas-film heat-transfer coefficients, it is necessary that the inlet water be at precisely the same temperature as the water leaving the packing. This necessitated a trial-and-error procedure. Conditions were considered satisfactory if the two temperatures were identical within ±0.2–0.3° F., although in the majority of tests the difference was less than ±0.1° F. The coefficients were corrected to 0° F. difference by following the main test with another short test in which the difference in water temperatures was ±1.0–2.0° F. data from which tests permitted application of the proper correction.

For tests with the inlet air temperature less than 120° F., the desired air temperatures were maintained to within ±0.10° F. by a Bristol proportioning-reset controller. For tests at higher temperatures manual control of a Spence pressure regulating valve maintained the inlet air temperature constant to within ±1–2° F. In these cases the inlet temperature driving force was generally greater than 100° F. Approximately 2–4 hrs. were required to adjust the inlet water to the proper value and the system to come to satisfactory thermal equilibrium. Actual test periods were from ¼–2 hr. in length, depending on constancy of conditions, during which period each thermometer was read about once every 5–7 min.

The most satisfactory procedure for determining the wet-bulb temperature was found to be the manual insertion of a wet-bulb soaked with water at approximately the actual wet-bulb temperature (±1° F.) into the air stream and observing the constant temperature value ultimately reached.

Discussion of Results

Heat Transfer. The observed heat-transfer coefficients, $h_G a_H$, are plotted against the gas rate (G) in Figures 3, 4, and 5 and are cross-plotted against the liquid rate (L) in Figure 6 for $Z = 6\frac{5}{16}$ in. The data, in general, correlate better than ±5% with certain evident exceptions. For $Z = 3\frac{1}{16}$ in., the curve for $L = 240$ lb./(hr.)(sq.ft.) appears to be displaced downward; for $Z = 6\frac{5}{16}$ in., $L = 240$ lb./(hr.)(sq.ft.), the curve was drawn in a manner consistent with later requirements for determining the end effects. These data are, as far as is known, just as accurate as any other series and no explanation is available for the apparent deviation. For $Z = 6\frac{5}{16}$ in. and $L = 6800$ lb./(hr.)(sq.ft.) the large circles indicate the estimated accuracy of the data. In these tests the exit air approached saturation and the driving forces were too small for accurate calculation of the coefficients.* Results of tests on $Z = 13\frac{1}{8}$ in. are presented in Figure 3. For the tests at $G = 180$ lb./(hr.)(sq. ft.) and L above 240 lb./(hr.)(sq.ft.) and for $L = 6800$ lb./(hr.)(sq.ft.), the exit driving forces were so small that accurate results were not possible. For the tests at $G = 100$ lb./(hr.)(sq.ft.) there was always a positive humidity driving force but there were negative temperature driving forces of the order of 0.40–0.75° F. (too large and consistent to be considered accidental or

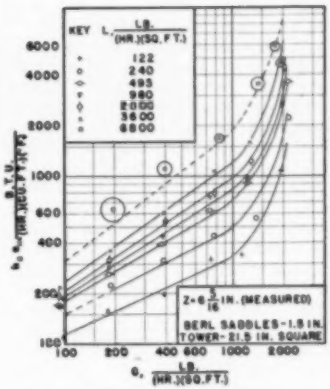

Fig. 4. Gas film heat-transfer coefficients, $h_G a_H$ vs. gas rate, G.

* A circle indicates the same degree of accuracy for both coordinates. Flow rates are considered accurate to within 1% and a vertical straight line would be proper. However, the circle is more readily observed and interpreted.

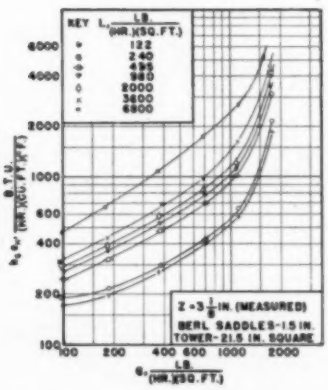

Fig. 5. Gas film heat-transfer coefficients, $h_G a_H$ vs. gas rate, G.

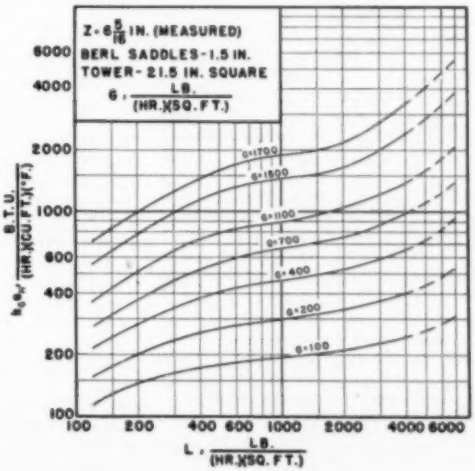

Fig. 6. Gas film heat-transfer coefficients, $h_G a_H$ vs. liquid rate, L.

observational errors) at the top of the tower, i.e., the inlet water was at a higher temperature than the exit air.

The heat balances for all runs closed within ±5–7% except for the very high and very low liquid rates. Careful analysis of the various factors involved leads to the conclusion that the smoothed heat-transfer data for the finite packing heights are accurate to ±5%.

To permit direct comparison of the data with those of other investigators, it was necessary to obtain true transfer coefficients for the packing only, which meant that the end-effects must be subtracted from the measured coefficients. Prior to completion of this study, McAdams et al. (*9*) indicated that a straight line could be expected if $h_G a_H$ were plotted against $1/Z$, permitting extrapolation to infinite packed height ($1/Z = 0$). It was anticipated that the data for $Z = 3\frac{1}{8}$ in. would facilitate the extrapolation, but unfortunately these values seem to be abnormally influenced by the end-effects and are not compatible with the others. This is illustrated in Figure 7, where the correlation obtained for the individual packing heights did not warrant a straight line extrapolation. (The method of Von Krevelen (*14*) proved unsatisfactory.) The results of the extrapolation are indicated in Figure 8. In this system, the transfer takes place readily and great packed depths can not be used for experimental work. The procedure followed, therefore, is a severe test of the data and although the curves of Figure 8 correlate the data within ±3%-5% or less, their accuracy is probably limited to ±10%-20%.

Table 1 presents the slopes of the observed and extrapolated data. The

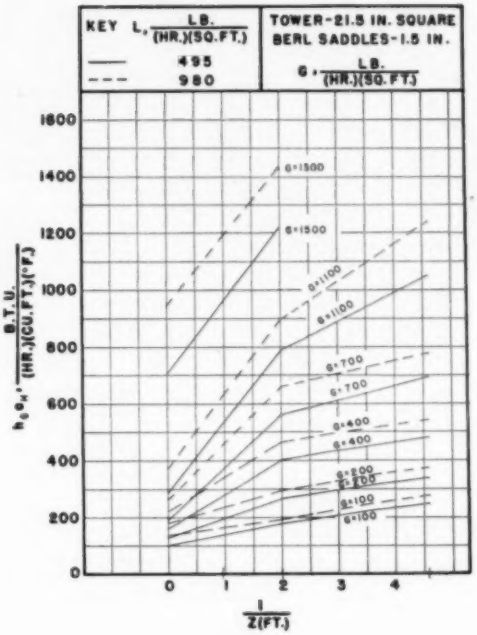

Fig. 7. Determination of true gas film heat-transfer coefficients, $h_G a_H$, by extrapolation to infinite packed height, Z (corrected).

exponent for the gas rate (n) is observed generally to decrease as Z increases, continuing this trend to infinite packing height. In absolute value these exponents range from 0.77 ($Z = 3\frac{1}{8}$ in.) to 0.26 ($Z = \infty$). Table 1 shows that for all cases an increase in liquid rate of about 55-fold causes a 50-80% increase in the gas rate exponent, n. However, as observed by McAdams et al. (*9*) in the range $L = 500 - 2000$ lb./(hr.)(sq.ft.) liquid rate has little effect on this exponent. Cross plots of $h_G a_H$ vs. L show a distinct ∫ shape curvature as in Figure 6. This same type of relationship had been previously reported by Dodge and Dwyer (*1*) in determining the effect of gas rate on the over-all gas-film mass-transfer coefficients. This trend is still apparent, although greatly diminished, at infinite packing height and, since it is very pronounced for $Z = 3\frac{1}{8}$ in., may possibly be a manifestation of end-effects. The average slope of these curves, even in the region $L = 500$–2000 lb./(hr.)(sq.ft.), is considerably greater than the value of 0.07 reported by McAdams et al. (*9*) and is of the same order of magnitude as reported by others for $h_G a_H$ estimated from work on absorption of highly soluble gases and water-cooling experiments. Increasing the gas rate about 17-fold generally doubled the gas-liquid rate exponent, m. It seems probable that if G could have been varied 50- to 60-fold a similar ∫ curvature might result. This possibility would seem worthy of investigation.

Above a gas rate of 700–900 lb./(hr.)(sq.ft.) the $h_G a_H$ increases rapidly for a small increase in G indicating that entrainment in the tower results in

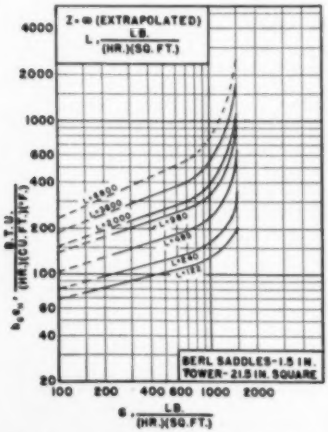

Fig. 8. True gas film heat-transfer coefficients, $h_G a_H$ vs. gas rate, G.

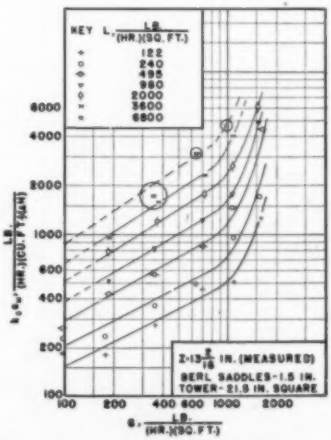

Fig. 9. Gas film mass-transfer coefficients, $k_G a_H$ vs. gas rate, G.

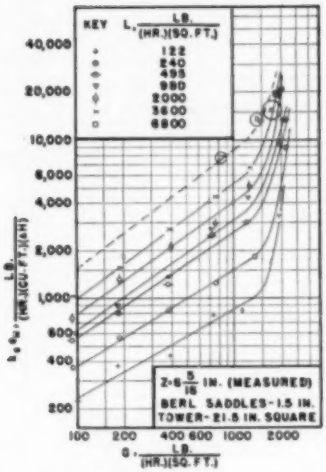

Fig. 10. Gas film mass-transfer coefficients, $k_G a_M$ vs. gas rate, G.

severe end-effects. The region in which the curves depart from straight lines is closely checked by the data of Fellinger (*4*) for the absorption of ammonia in water. Beyond G = 1600–1700 lb./(hr.)(sq.ft.) loading occurs and entrainment becomes so severe that the exit air approaches saturation.

Mass Transfer. The observed mass-transfer coefficients, $k_G a_M$, were plotted against G (Figs. 9 and 10 are typical) and cross-plotted against L (Figs. 11 and 12 are typical). The data correlate

TABLE 1.—SUMMARY OF EFFECT OF L AND G ON $h_G a$ AND $k_G a$ †

$Z = \infty$

$h_G a_H$ vs. G		$h_G a_H$ vs. L			$k_G a_M$ vs. G		$k_G a_M$ vs. L	
L	n	G	m	m	L	n'	G	m'
122	0.26	100	.34	.24	122	.31	100	.46
240	0.27	200	.36	.39	240	...	200	.46
495	0.33	400	.39	.45	495	...	400	.48
980	0.34	700	.42	.50	980	.35	700	.50
2000	0.34	1100	.47	.58	2000	.38	1100	...
3600	0.39	1500	.67	.66	3600	.43	1500	...
6800	0.44	....	...	...	6800	.45	....	...
		L = 120 to 1000		L = 2000 to 6800				

Z = 13½ in.

$h_G a_H$ vs. G		$h_G a_H$ vs. L			$k_G a_M$ vs. G		$k_G a_M$ vs. L	
L	n	G	m	m	L	n'	G	m'
122	.40	100	.23	.24	122	.51	100	.44
240	.42	200	.35	.31	240	.52	200	.46
495	.50	400	.43	.35	495	.57	400	.49
980	.52	700	.46	.38	980	.60	700	.52
2000	.53	1100	.52	.50	2000	.63	1100	.58
3600	.59	1500	.65	.71	3600	.65	1500	.57
6800	.63	1700	.78	...	6800	.67	1700	...
		L = 120 to 700		L = 2000 to 6800				

Z = 6 5/16 in.

$h_G a_H$ vs. G		$h_G a_H$ vs. L			$k_G a_M$ vs. G		$k_G a_M$ vs. L		
L	n	G	m*		L	n'	G	m'*	
122	.46	100	.11	curve	122	.58	100	.33	curve
240	.50	200	.16	∫	240	.60	200	.35	∫
495	.59	400	.20		495	.66	400	.38	
980	.63	700	.22		980	.69	700	.40	
2000	.66	1100	.22		2000	.71	1100	.42	
3600	.71	1500	.22		3600	.74	1500	.48	
6800	.77	1700	.22	shaped	6800	.75	1700	.55	shaped
		L = 500 to 2000					L = 500 to 3600		

Z = 3½ in.

$h_G a_H$ vs. G		$h_G a_H$ vs. L			$k_G a_M$ vs. G		$k_G a_M$ vs. L		
L	n*	G	m*		L	n'*	G	m'*	
122	0.58	100	0.13	curve	122	0.65	100	0.27	curve
240	0.58	200	0.14	∫	240	0.66	200	0.30	∫
495	0.64	400	0.15		495	0.65	400		
980	0.64	700	0.15		980	0.64	700		
2000	0.65	1100	0.16		2000	0.67	1100	0.28	
3600	0.67	1500	0.20		3600	0.71	1500		
6800	0.71	1700	0.22	shaped	6800	0.92	1700	0.29	shaped
		L = 500 to 2000							

† This table presents a summary of the exponents to be used in equations representing the heat- and mass-transfer coefficients as exponential functions of the gas and liquid rates, i.e., $h_G a_H = a(G)^n(L)^m$ and $k_G a_M = a(G)^{n'}(L)^{m'}$. With the exception of the data for $Z = \infty$, these values represent smoothed curves through the observed data.

* These values are only approximate since the data plotted on log-log coordinates show a marked curvature.

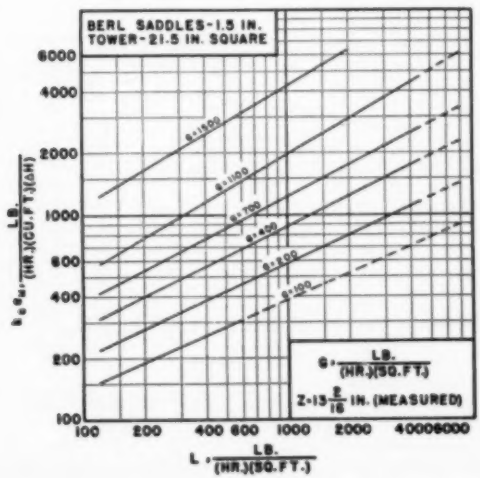

Fig. 11. Gas film mass-transfer coefficients, $k_G a_M$ vs. liquid rate, L.

well and based on the discussion in the preceding section may be considered generally to be accurate to within ±5–10%, with a few marked deviations from the general trends. For example, the coefficients for L = 240 and 120 lb./(hr.)(sq.ft.) in Figure 9 correlate poorly and are generally lower than would be expected. It is thought that, for an unaccountable reason, these data scatter a bit more than the others and a study of the ratio $h_G a_H / k_G a_M$ calculated from the actual test data seem to confirm use of the best straight line through the points.

For Z = 3½ in. (not shown) a plot of $k_G a_M$ vs. G is similar to Figure 5 for $h_G a_H$ both in the shape of the curves and in the excellent correlation of the data. A plot of $k_G a_M$ vs. L also shows a pronounced ∫ shape.

The extrapolation to infinite packing heights is less satisfactory than for heat-transfer because the observed mass-transfer coefficients are much more diffi-

cult to obtain and the greater slope reduces the accuracy; extrapolation was unsatisfactory for $L = 240$ lb./(hr.)(sq.ft.) and $L = 495$ lb./(hr.)(sq.ft.). Results are presented in Figure 13. The extrapolated points scatter only ±5–10% but the accuracy of these data may be only ±30%, certainly not satisfactory for use in the desired general correlation discussed in the introduction.

In general the observed mass-transfer coefficients are two to three times larger than the heat-transfer coefficients and are affected more by liquid and gas rates as indicated by the greater slopes (Table 1). The region in which L has virtually no effect on $k_G a_M$ is much smaller than for $h_G a_H$, and for $Z = 13\frac{1}{8}$ in. (Fig. 11) has disappeared. This is in contrast to $h_G a_H$ vs. L for $Z = 13\frac{1}{8}$ in. in which the general $\int$ shape is still evident.

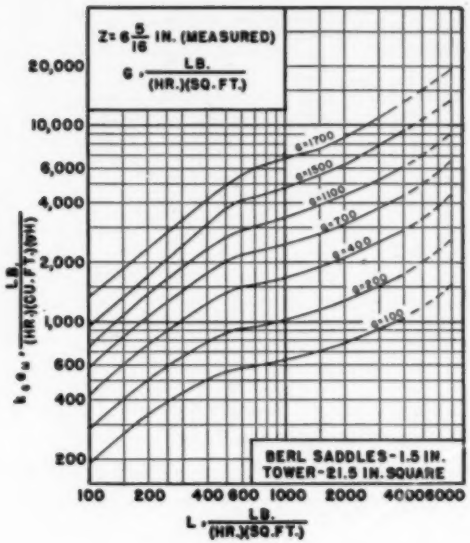

Fig. 12. Gas film mass-transfer coefficients, $k_G a_M$ vs. liquid rate, L.

Apparent Psychrometric Ratio. In the wet-bulb equation the ratio of the heat- and mass-transfer coefficients, h_G/k_G, is called the psychrometric ratio and, for the system air-water, it is approximately equal to the humid heat, $c_s = 0.24$ B.t.u./(lb.)(° F.). Thus, if a_H were equal to a_M for packed towers, the apparent psychrometric ratio, $h_G a_H/k_G a_M$, would approximate the humid heat. Values of this ratio were calculated from the smoothed data and plotted in Figures 14 and 15. These data confirm the qualitative observations of McAdams et al. (9) that the value is not constant.

The ratio h_G/k_G should be independent of L, G, and Z and any increase in the apparent psychrometric ratio is probably the result of an increase in the ratio a_H/a_M (9). From Figures 14 and 15 it is seen that as both the liquid rate and the gas rate decrease, the value of $h_G a_H/k_G a_M$ increases. At high liquid and gas rates the packing becomes completely wetted, a_H and a_M are essentially equal, and the apparent psychrometric ratio, $h_G a_H/k_G a_M$, approaches a minimum value of 0.23–0.24 which is a satisfactory large-scale verification of the value of the psychrometric ratio for the system air-water obtained by analysis of Dropkin's (2) data presented under "Humidity Determination." As the rates decrease, the packing becomes incompletely wetted resulting in more area available for heat transfer than for mass transfer. The approximate limit of this process is reached when $a_H/a_M = 2$. The resulting maximum value of $h_G a_H/k_G a_M$ is about 0.5 for the system air-water. Only in the doubtful region of very low L and G for $Z = 13\frac{1}{8}$ in. is this value exceeded and even these data are less than 0.58. Thus, the high values indicated for $Z = \infty$ (Fig. 15) are considered incorrect and probably result more from inaccurate extrapolated mass-transfer rather than heat-transfer coefficients.

Adiabatic Isothermal-Saturation Temperatures. McAdams et al. (9) observed that in packed towers at low gas rates the adiabatic isothermal water temperature was 1–3° F. higher than the adiabatic saturation temperature and the difference increased as G decreased. This phenomenon was verified in this investigation and, since lower air and liquid rates were employed, temperature differences as great as 5–6° F. were observed (Fig. 16). A considerable effect of L is observed with the temperature difference increasing with decreasing liquid rate. There is also a significant increase in the temperature difference as the packed height, Z, increases.

Scattering of these data is a further indication that the inlet humidity measurements are probably the main source of error in this investigation.

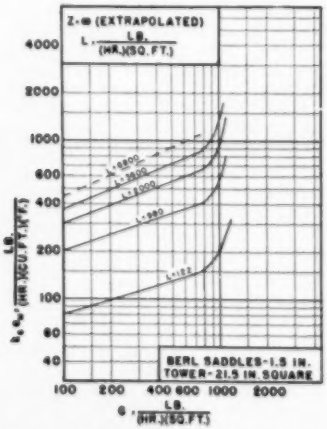

Fig. 13. True gas film mass-transfer coefficients, $k_G a_M$ vs. gas rate, G.

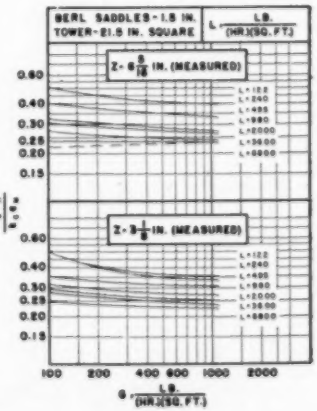

Fig. 14. The apparent psychrometric ratio, $h_G a_H/k_G a_M$ measured in a packed tower.

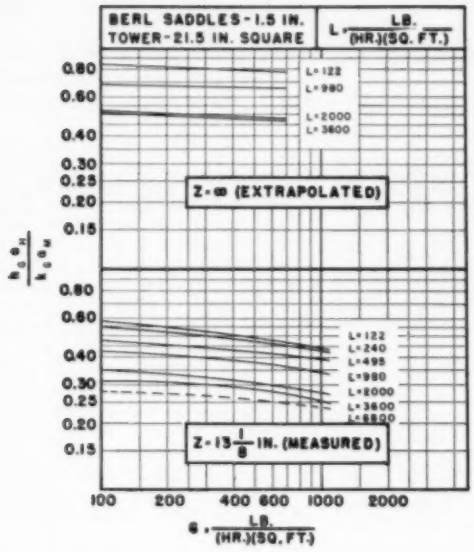

Fig. 15. The apparent psychrometric ratio, $h_G a_H / k_G a_M$ measured in a packed tower.

Summary and Conclusions

Heat- and mass-transfer coefficients were investigated for countercurrent adiabatic contact of air and water in a packed tower under the following conditions:

a. Temperature of the water phase maintained constant throughout the tower
b. Packed heights of 3⅛, 6⅞₁₆, and 13⅛ in. of 1½-in. Berl saddles
c. Liquid rates $L = 120$ to 6800 lb./(hr.)(sq.ft.)
d. Gas rates $G = 100$ to 1900 lb./(hr.)(sq.ft.)
e. Inlet air temperatures 100° to 260° F.

Unique features of the experimental equipment include:

a. Large, square tower 21.5 in. on a side
b. Uniform water distribution to every 1.13 sq.in. of tower cross section
c. Uniform inlet air distribution to the four sides of the tower
d. Successful elimination of entrained water from the exit air sample

Directly observed heat ($h_G a_H$) and mass ($k_G a_M$) transfer coefficients for the gas film are presented and are considered accurate to within ±5% and ±10% respectively.

Extrapolation of the observed data to infinite tower height, in order to eliminate end-effects, gave results which are considered less accurate: ±10%-20% for $h_G a_H$ and ±30% for $k_G a_M$.

When the transfer coefficients are expressed as power functions of $L + G$, it was found that: (a) L has a considerable direct effect on the transfer coefficients and a lesser but still important effect on the exponent for G; (b) G affects the coefficients directly and influences the exponent on L as well, more so for $h_G a_H$ than for $k_G a_M$.

The apparent psychrometric ratio, $h_G a_H / k_G a_M$, for a packed tower is neither constant nor equal to the humid heat of the main air stream, as frequently supposed. Rather it varies from 0.23 to 0.58, depending upon flow rates and packed height.

The adiabatic isothermal temperature of the liquid may be appreciably higher, as much as 6° F., than the adiabatic saturation temperature of the inlet air due to the inequality of a_H and a_M.

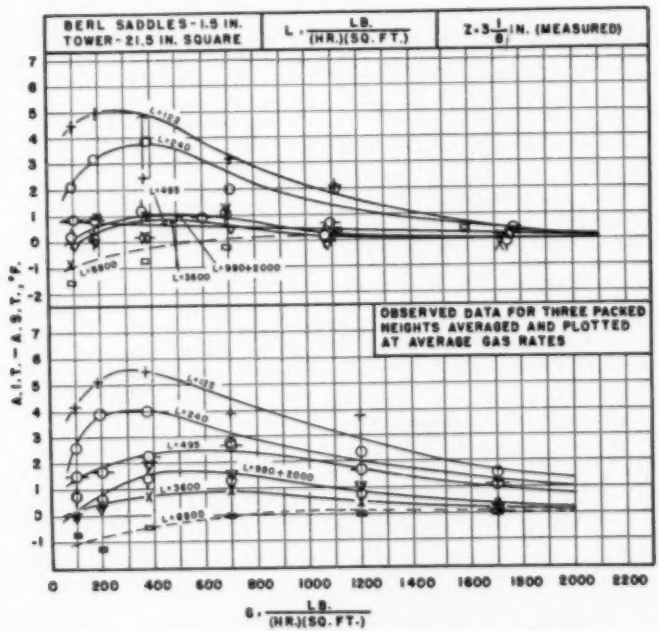
BERL SADDLES - 1.5 IN.
TOWER - 21.5 IN. SQUARE
L = LB./(HR.)(SQ. FT.)
Z = 13 1/8 IN. (MEASURED)
OBSERVED DATA FOR THREE PACKED HEIGHTS AVERAGED AND PLOTTED AT AVERAGE GAS RATES
A.I.T. - A.S.T., °F.
L=122
L=240
L=495
L=980+2000
L=3600
L=8800
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200
G = LB./(HR.)(SQ. FT.)

Fig. 16. Difference between the adiabatic isothermal temperature and the adiabatic saturation temperature for a packed tower.

Acknowledgment

This work was performed under an Industrial Fellowship at New York University provided by Maurice A. Knight of Akron, Ohio.

Abstracted from thesis of S. L. Hensel, Jr., submitted in partial fulfillment of requirements for the degree of D.Eng.Sci., New York University.

Notation

a = interface area per unit volume of packing, sq.ft./cu.ft.

c = specific heat at constant pressure, B.t.u./(lb.)(° F.)

c_s = humid heat of humid air at constant pressure, B.t.u./(lb. dry air)(° F.)

D_v = diffusivity in vapor, sq.ft./hr.
G = mass velocity of dry air, lb. dry air/(hr.)(sq.ft.)
H = humidity, lb. water vapor/lb. dry air
H_s = saturated humidity, lb. water vapor/lb. dry air
h = coefficient of heat transfer, individual, B.t.u./(hr.)(sq.ft.)(° F.)
ha = coefficient of heat transfer, individual, B.t.u./(hr.)(cu.ft.)(° F.)
k = mass-transfer coefficient, individual, lb./(hr.)(sq.ft.)(ΔH)
ka = mass-transfer coefficient, individual, lb./(hr.)(cu.ft.)(ΔH)
k_{th} = thermal conductivity, B.t.u./(hr.)(sq.ft.)(° F./ft.)
L = mass velocity of liquid, lb./(hr.)(sq.ft.)
M = molecular weight
P = pressure, total, lb. force/sq.ft. or atm.
p = pressure, partial, lb. force/sq. ft. or atm.
T = temperature, abs., ° R.
t = temperature, ° F.
Z = height of packing, ft.
a = angle of inclination or radiation correction to the wet bulb
λ = latent heat of vaporization of water, B.t.u./lb.
ρ = density, lb./cu.ft.

SUBSCRIPTS:

1 = bottom of tower or upstream of orifice
2 = top of tower or downstream of orifice
A = dry air
$av.$ = arithmetic average
Bm = log-mean average
f = value of variables halfway through effective film, B
G = gas phase (except for D_v, diffusivity in gas phase)
H = humid air or heat transfer as in $h_G a_H$
i = interface values
L = liquid phase
M = main body of gas stream or mass transfer as in $k_G a_M$
S = saturation conditions (air with water)
s = indicates humid heat, i.e., specific heat of humid air, c_s
th = thermal conductivity, k_{th}
v = diffusivity in gas phase (D_v)
W = water vapor
Wb = wet bulb

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Discussion

Joseph Byrne (MIT Station, Bethlehem Steel Co., Lackawanna, N. Y.): What would you expect the effect of diameter of your tower to have on the coefficient which you have found?

S. L. Hensel, Jr.: The tower was 21½ in. on a side and 1½ in. Berl saddles were employed, which is way beyond the usual ratio of 8:1 that is considered satisfactory. I would not think that, as the tower diameter got larger, there would be any effect of the ratio of the packing main dimension to tower main dimension on these coefficients.

Joseph Byrne: The reason for my question is based on a study of benzene in lubricating oil which is a typical process in coke-oven by-products work. In the laboratory, with approximately the same ratio of packing size to column size, the height of a theoretical plate, for example, might be 2 in. in a column 3 or 4 in. in diam.; whereas we find plant equipment (diam. of 12 to 16 ft.) will have a height of theoretical plate of 15 to 20 ft.

S. L. Hensel: Were those packed towers?

Joseph Byrne. These were packed towers.

S. L. Hensel: Was the liquid distribution as efficient in the plant as it was in the laboratory?

Joseph Byrne: I would say that it was not. That would be the interpretation of the data, which would usually arise. In your case, with short packing, I would be able to expect good distribution. How about distribution if the depth of the packing is increased?

S. L. Hensel: Well, the distribution initially, in all three cases, was very good as you can see—400 openings, i.e., 1.15 sq. in. of tower cross-section area/opening. I have seen some work—I can't remember where—on the effect of packed types on distribution. With Berl saddles the tendency to channeling is indicated to be much less than for rings and some other types of packing. In other words, if the liquid is initially distributed satisfactorily, certainly in one foot you would not expect any unsatisfactory distribution. Now what will happen at 12 to 15 ft.? I don't know. That could be another explanation for the poor performance of the plant vs. the laboratory work rather than the ratio of packing diameter to tower diameter, plus the much poorer liquid distribution that usually results in a plant installation.

G. M. Davis (Du Pont Co., Inc., Niagara Falls, N. Y.): Does your last slide represent the temperature difference between the water leaving the tower and the air entering?

S. L. Hensel: No. That was a plot of adiabatic isothermal temperature minus the adiabatic saturation temperature vs. gas rate for various liquid rates. The latter, of course, is uniquely determined by the temperature and humidity of the inlet air. The former is the equilibrium liquid temperature reached by adiabatically recirculating the exit liquid until the inlet and exit liquid temperatures are identical. For spray towers, where the areas available for heat and mass transfer are identical, the liquid temperature reached by adiabatic recirculation is the adiabatic saturation temperature of the inlet air. For packed towers these areas are generally not the same and the isothermal liquid temperature is greater than the adiabatic saturation temperature.

G. M. Davis: It becomes apparent that the temperature difference between water leaving the tower and adiabatic saturation temperature of entering air is the same as the term "approach" used in cooling tower industry. The data do not include conditions of leaving air. Was the leaving air saturated?

S. L. Hensel: In order to calculate coefficients, the air had to leave unsaturated since log mean driving forces were involved. That was the difficulty at high packed heights and flow rates.

(Presented at A.I.Ch.E., Rochester (N.Y.) Meeting.)

Clear philosophic approaches to chemical engineering and chemical engineering education are rare . . . but here is one that will be read with interest by educator, graduate, student, and executive . . . we think the author's comment about what is important in engineering problems will be read, quoted and used for many years . . .

WHAT TYPE EDUCATION—

SPECIALIZED OR FUNDAMENTAL?

JAMES H. BOYD

Chemical Engineer, New York, New York

SHOULD there be two undergraduate curricula in chemical engineering, one directed toward specialization and the other toward more general fundamental instruction? This is an important question today, and in examining it, this article will be confined solely to a four-year program of study leading to the B.S. degree. Typically, such a program requires eight terms and one summer session for completion. The first two scholastic years usually consist of prescribed studies in the humanities, chemistry, mathematics, and physics. The summer session follows wherein industrial stoichiometry is taught by lecture and laboratory studies directed to the chemical engineering analysis of inorganic processes. The last two years concentrate on chemical engineering studies, chemistry, supplementary engineering subjects and a few electives. If there are to be two undergraduate curricula the differentiation must probably be confined to the junior and senior years. One curriculum is to be broadly fundamental and the other is to give specialized or more intensive instruction in strictly chemical engineering subjects.

U. S. vs. Germany

What is chemical engineering? It is the conscious application of science to industrial and commercial activities based primarily on chemical reactions. The industrial recognition of the profit possibilities of chemical operations created a demand for technologists trained to aid in bringing a laboratory chemical dream to commercial fruition. The first demand was for men to design apparatus suitable for chemical plant manufacturing operations. In Germany, where industrial chemistry had its origins, this demand was met by the joint efforts of chemists and mechanical engineers with the former controlling. The practical result was the development of large-scale apparatus bearing in many instances a strong resemblance to laboratory vessels. This was a workable arrangement and led to the creation of a large, highly integrated, chemical industry whose achievements were the manufacture of synthetic dyestuffs and pharmaceuticals, nitrogen fixation, coal hydrogenation and synthetic rubber. For a time, Germany was beyond dispute the leading chemical nation of the world, and World War I brought home to her opponents, all too sharply, their chemical dependence on Germany. This war-born necessity stimulated the growth of the infant chemical industry in the United States and also the demand for personnel to expand it and to man it. The need for numerous chemical engineers came practically overnight and at a time when the opportunity to draw on German experience was nil.

Likewise the philosophy of American chemical engineering education developed rapidly and independently. The evolution of the new profession, chemical engineering, as we know it, was swift. The now familiar concept of "unit operations" came into being and provided a powerful tool for the rational design and intelligent operation of chemical plants. The teaching of unit operations led to the evolution of a chemical engineer who combined a grasp of the fundamentals of chemistry, physics, and mathematics, and the technique of the application of this knowledge to industrial operations. This was a distinct advance over the German method.

Growth and Its Concomitants

As chemical industry expanded, competition increased and spurred the study of the economics of chemical operations. As this economic analysis progressed, it was recognized that chemical manufacturing costs are usually controlled by the cost of raw materials, of energy, and of the capital employed. The cost

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of labor is usually less important. Under the free enterprise system there is continued pressure for more efficient processes which will give lower manufacturing costs. This economic compulsion leads to new products as well as new processes. In this country the development of the unique petrochemical industry has provided spectacular examples of both new products and new processes to make them—new products such as ethylene glycol, ethylene oxide and the host of their derivatives which include the alkanolamines, alkyl ethers of glycol and the lower polyglycols, and the surfactants which are ethylene oxide adducts. American process developments are the chlorhydrin method for glycol and the direct oxidation of ethylene with air to ethylene oxide. Then the realization dawned of the need and difficulties of bringing these new products from laboratory curiosities to full-fledged commercial commodities.

In its broader sense chemical engineering includes research and the discovery of knowledge and its application not only to the manufacture but also to the sale of chemical products. Thus it includes the development of equipment and methods of manufacture in so-called pilot plants. While these units are built and operated primarily to obtain process data for plant design and economic appraisal of the project, they are also useful in furnishing substantial samples for establishing uses, specifications, and values of the new products. Frequently these products require modification to make them more useful or more valuable. These changes in product may require changes in process and plant design. Such chemical process and commercial development work enables evaluation of a project, on the basis of studied estimates of cost of plant facilities, cost of manufacture, market values and volumes, and permits a projection of the profits earned on the investment.

Sales and the Technical Man

If this study is deemed sound and yields a favorable conclusion, and if the funds and personnel are available, executive decision to proceed can properly be made. Sale of the product is presumed. But to sell the new product requires the aid of a technical man thoroughly acquainted with its merits, limitations, and potential uses. Only after use of the product is established can the sales properly be handled by the sales department, and here too technical personnel are needed to comprehend the customers' needs and criticisms. Further, the administration of a company engaged in chemical business requires technical personnel at the management level. All these activities lie within the field of chemical engineering and organized chemical engineering education is the customary and most efficient means of preparing young men and women for work in this field.

Engineers are all too often inferior in the exposition of technical ideas. The imperfect communication of their ideas to others in spoken or written English is a major handicap. The accurate and persuasive expression of ideas makes them valuable, but without explicit statement they are usually of little or no value. Facility in the use of the English language can be taught.

This organized educational program consists of undergraduate and graduate studies, but we are concerned here with only the undergraduate program or curriculum. Cooperative plans of study are not considered. Only a full-time, four-year undergraduate curriculum is discussed here and the author strongly favors fundamental training and avoidance of specialization at the undergraduate level.

Value of Basic Knowledge

So fundamental a curriculum is aimed primarily at helping the student acquire a foundation of scientific and technical knowledge not readily gained by independent study or by working in industry. The student should use the university to get instruction in those subjects wherein it is superior. This is simply engineering efficiency. The successful pursuit of many subjects is more efficient and more effective in group study with qualified instruction than when undertaken alone. The mastery of fundamentals so acquired provides a foundation of basic scientific knowledge and of skill in its engineering application to make further learning easier and more profitable whether in industry or in graduate study.

A greater mastery of fundamentals is preferable to a wider but necessarily less thorough acquaintance with more advanced subjects e.g., short courses in catalysis, heat transfer, and distillation; in essence, fewer but more intensive courses of study. Such a curriculum will not satisfy the need of the scholastically ambitious student, but it will provide the best of foundations for graduate study. For those going into industry this fundamental curriculum will provide the best basis for the successful acquisition and integration of industrial experience.

Obviously such a curriculum does not provide the student with any real grasp of industrial techniques and know-how. That is not the intention. Those will be better learned in industry where the subject matter is living and up to date.

The fundamental curriculum does not prepare the man with a B.S. in chemical engineering for any specific job. To do so would require a sacrifice in fundamental knowledge with a subsequent handicap in this regard. The object of undergraduate training is not to give the student all the answers but rather the methods of observation and thinking which will lead him to the answers. While our students gain facility in the application of scientific and engineering principles through problem work, we recognize that these problems are packaged and delivered to the student without effort on his part. Not infrequently this leads to the belief by the student that the engineering solution of a problem is more difficult than its recognition and definition. The converse is the fact. The problems encountered in industry are usually broad and unstated, and frequently indefinite and intermingled. The analysis of these more or less confused situations and their resolution into one or more discrete problems is almost invariably more demanding than the pertinent engineering solutions. The power to do this work rests on a mastery of principles rather than on a great proficiency in engineering calculations. While the latter is a necessary tool, it is only a tool. It is merely the servant of the ability to isolate and state the problem. It is the over-all ability not only to find the problems but also to solve them which is highly rewarded. This over-all ability is usually the result of building a fruitful industrial experience on a strong foundation of scientific knowledge. This strong foundation of scientific knowledge can be acquired best in college. The fruitful industrial experience can be acquired only in industry. The industrial experience would include a knowledge of the chemical and economic factors of raw material supply, chemical conversion, and commercial utilization of products plus an awareness

We have taken for granted the integrity and honesty of the engineer. Certainly these qualities are necessary to command that confidence and loyalty of associates on which a successful career depends . . . Certainly the B.S. in chemical engineering should possess honesty, integrity, and moral fiber. Without them it is easy to envision a deterioration in the quality of scientific research, of engineering, and of commercial operations.

of the long-range company policies. Such knowledge is essential to good judgment. This good judgment combined with a mastery of scientific and engineering fundamentals, equips the engineer for major industrial responsibilities.

The question is whether two undergraduate chemical engineering curricula are desirable. One of the two will be directed to giving the surest mastery of the basic scientific and engineering principles with a leavening of humanities to facilitate the student's integration of his engineering with the social and economic world around him. The second curriculum pretending to a useful specialization by the undergraduate must fail in its purpose. Professional specialization prior to the junior and senior years is a practical impossibility. Probably none can be given before the senior year. The time limitation of the undergraduate curriculum does not permit thorough training of an undergraduate in a professional specialty. Through no fault of his own he would fail to master the professional specialties which would prove indigestible because of premature presentation and inadequate time for assimilation. Then, too, if professional specialization is to be offered the undergraduate, there is a teaching problem to be considered. It would seem these professional courses should be taught in two sections, one undergraduate and the other graduate, since a watered-down undergraduate version would not be suitable for the graduate students. Conversely a good, intensive professional course would require more time than the undergraduate could give it.

Thus for good instruction in a single subject, two courses, one graduate and one undergraduate, would be required. This would mean a doubling of the teaching burden for a single professional subject. The end does not justify the cost in teaching effort. The increased emphasis on undergraduate specialized professional training would defeat itself. At best the graduate from a professional undergraduate course would have only a narrow outlook limited by the scope of his specialization. He would lack the scientific foundation necessary for subsequent professional development. Advanced professional subjects are properly taught at the graduate level. The students are more mature, purposeful and ready for the greater intensity of effort necessary for successful advanced professional training. A contributing factor to the question of dual curricula has been the recent increasing participation of chemical engineers in commercial activities. Some have advocated special undergraduate courses for chemical engineers aiming toward commercial work but here again the classroom is no substitute for chemical commercial experience. The value of experienced chemical engineers in commercial activities rests basically on their contribution in coordinating the commercial and technical factors of practical problems and in interpreting the significance of the technical factors to the commercial personnel and of the commercial factors to the technical personnel. The latter may be in research, process development, plant process engineering or manufacturing. To carry weight the chemical engineer interpreter must command in technical matters the respect of the technical personnel with whom he deals. Therefore he must have a strong technical background. To dilute or lessen the undergraduate's purely technical education for the sake of premature college instruction in commercial subjects will handicap him ultimately in commercial chemical development work.

I favor a single undergraduate chemical engineering curriculum directed toward the broader basic studies and I am against adding one seeking professional specialization at the undergraduate level. However, there are still weaknesses in the best of undergraduate chemical engineering curricula.

While our students gain facility in the application of scientific and engineering principles through problem work, we recognize that these problems are packaged and delivered to the student without effort on his part. Not infrequently this leads to the belief by the student that the engineering solution of a problem is more difficult than its recognition and definition. The converse is the fact. The problems encountered in industry are usually broad and unstated, and frequently indefinite and intermingled. The analysis of these more or less confused situations and their resolution into one or more discrete problems is almost invariably more demanding than the pertinent engineering solutions.

Engineers are all too often inferior in the exposition of technical ideas. The imperfect communication of their ideas to others in spoken or written English is a major handicap. The accurate and persuasive expression of ideas makes them valuable, but without explicit statement they are usually of little or no value. Facility in the use of the English language can be taught. Here is an opportunity for improvement in undergraduate chemical engineering education.

We have taken for granted the integrity and honesty of the engineer. Certainly these qualities are necessary to command that confidence and loyalty of associates on which a successful career depends. The basketball bribery scandals and the recent major group violation of the West Point honor code may be symptomatic of a serious lack in the education of young men in all fields. Certainly the B. S. in chemical engineering should possess honesty, integrity, and moral fiber. Without them it is easy to envision a deterioration in the quality of scientific research, of engineering, and of commercial operations. These virtues may best be instilled by example and by insistence on them in the day-to-day college work. There is another lack in the basic undergraduate curriculum. This is a course in common sense. However, if offered as an elective, it would have no enrollment. No one has ever complained of being deficient in common sense. And where would you find a qualified teacher?

It appears that a curriculum aiming at giving an integrated basic scientific training broad in scope is the best undergraduate chemical engineering curriculum developed to date. Certainly undergraduate chemical engineering training can be improved, but not by atempting to develop an undergraduate course of pseudoprofessional aspirations.

Contribution No. 25 from the Chemical Engineering Laboratories, Engineering Center, Columbia University.

(Presented at A.I.Ch.E. Rochester (N. Y.) Meeting).

CORRECTION

In "An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and Their Mixtures," by Messrs. Benedict, Webb and Rubin, printed in the September, 1951, issue of "C.E.P.," an error occurs in Equations (17) and (18) on page 450. They should be as follows:

$$P = RTd + [B_oRT - A_o - C_o/T^2]d^2 + [bRT - a - c/T^2]d^3 \qquad (17)$$

$$RT \ln f_j/y_j = RT \ln dRT + [(B_o + B_{oj})RT - 2(A_oA_{oj})^{1/2} - 2(C_oC_{oj})^{1/2}/T^2]d + \frac{3}{2}[(b^2b_j)^{1/3} - (a^2a_j) + (c^2c_j)^{1/3}/T^2]d^2 \qquad (18)$$

PLASTICS EQUIPMENT REFERENCE SHEET

RAYMOND B. SEYMOUR and EARL A. ERICH

Atlas Mineral Products Co., Mertztown, Pa.

RIGID POLYVINYL CHLORIDE: This unfilled and unplasticized plastic is available from domestic and foreign sources as 9 ft. x 4 ft. sheet in ⅛ in., 3/16 in. and ¼ in. thicknesses and as ½ in., ¾ in., 1 in., 1½ in. and 2 in. pipe. Bolts, nuts, elbows, T's, couplings and flanges are also available commercially.

APPLICATION AND REMARKS: Sheet may be formed, drawn or welded to yield chemical resistant structures, such as ducts, hoods, plenum chambers, stacks, splash covers and tanks.

CHEMICAL COMPOSITION: Essentially 100% polyvinyl chloride with appropriate pigment and stabilizer.

MACHINABILITY: Can be formed by the use of dies or blowing techniques, welded by hot gas process using polyvinyl chloride welding rod, heat-sealed, cemented, ground, turned, sanded, stamped, drilled and milled. Since it is thermo-plastic, a coolant is recommended in many machining operations. Saws should have fine teeth without set, the following tool angles are recommended: lead 60°, cutting 15-20°, relief angle 8-10°. This plastic should be formed or rolled and deep-drawn at 280-320° F. Heat formed parts should be annealed for 16 hrs. at 140° F. Sheet should be welded at 365-390° F.

TEMPERATURE LIMITATIONS: Not recommended for continuous service at temperatures above 160° F.

MECHANICAL AND PHYSICAL PROPERTIES:

Tensile Strength, lbs./sq.in @	
55° F.	14,000
75° F.	9,000
100° F.	3,000
Elongation %	5-40
Impact Notch, Izod lb./in.	0.6
Hardness, Rockwell R	110-120
Flexural Strength, lbs./sq.in. @	
55° F.	25,000
75° F.	16,000
100° F.	6,000
Compressive Strength, lbs./sq.in.	10,000
Modulus of Elasticity (x 10^5 lbs./sq.in)	4
Specific Gravity	1.4
Heat Distortion (°F.)	175
Specific Heat (B.t.u./(lb.) (°F.) (70-150° F.)	0.4
Thermal Expansion (in./in. °F. x 10^{-6} (70-120° F.)	4
Thermal Conductivity B.t.u./(sec.) (sq.ft.) (°F./in. x 10^{-4}) (70-120° F.)	3
Insulation Resistance @ 120° F. (1/32 in. megohms/1000 ft.)	30,000

CORROSION RESISTANCE

	C	H
ACIDS		
Acetic 10%	E	G
Acetic, glacial	E	P
Benzene sulfonic	E	E
Benzoic	E	E
Boric	E	E
Butyric	F	N
Chloroacetic	E	G
Chromic 10%	E	E
Chromic 50%	E	G
Citric	E	E
Fatty acids	E	P
Fluosilicic	E	E
Formic	E	P
Hydrobromic	E	E
Hydrochloric	E	E
Hydrocyanic	E	E
Hydrofluoric	E	E
Hypochlorous	E	E
Lactic	E	E
Maleic	G	F
Nitric 5%	E	E
Nitric 20%	E	E
Nitric 40%	E	G
Oleic	E	G
Oxalic	E	E
Perchloric	E	E
Phosphoric	E	E
Picric	P	N
Stearic	E	E
Sulfuric 50%	E	E
Sulfuric 70%	E	F
Sulfuric 93%	E	F
Oleum	F	P
Mixed Acids 57% H_2SO_4 26% HNO_3	E	G
ALKALIES		
Ammonium hydroxide	E	E
Calcium hydroxide	E	E
Sodium hydroxide	E	E
Potassium hydroxide	E	E
ACID SALTS		
Alum or Aluminum sulfate	E	E
Ammonium chloride, nitrate, sulfate	E	E
Copper chloride, sulfate	E	E
Ferric chloride, sulfate	E	E
Nickel chloride, sulfate	E	E
Stannic chloride	E	E
Zinc sulfate	E	E
ALKALINE SALTS		
Barium sulfide	E	E
Sodium carbonate	E	E
Sodium bicarbonate	E	E
Sodium sulfide	E	E
Trisodium phosphate	E	E
NEUTRAL SALTS		
Calcium chloride	E	E
Calcium sulfate	E	E
Magnesium chloride	E	E
Magnesium sulfate	E	E
Potassium chloride, sulfate	E	E
Sodium chloride, sulfate	E	E
GASES		
Chlorine wet	E	G
Chlorine, dry	E	E
Sulfur dioxide dry	E	E
Sulfur dioxide wet	E	E
ORGANIC MATERIALS		
Acetone	N	N
Alcohol, methyl, ethyl	E	E
Aniline	N	E
Benzene	P	N
Carbon tetrachloride	N	N
Chloroform	N	N
Ethyl acetate	N	N
Ethylene chloride	N	N
Formaldehyde	E	E
Phenol 5%	E	G
Refinery crudes	E	G
Trichloroethylene	N	N
PAPER MILL APPLICATIONS		
Kraft liquor	E	E
Black liquor	E	E
Green liquor	E	E
White liquor	E	E
Sulfite liquor	E	E
Chloride bleach	E	G
Alum	E	E
PHOTOGRAPHIC INDUSTRY		
Developers	E	G
General use	E	G
Silver nitrate	E	G
FERTILIZER INDUSTRY		
General Use	E	E
STEEL		
Sulfuric acid pickling	E	E
Hydrochloric acid pickling	E	E
H_2SO_4-HNO_3 pickling	E	E
TEXTILE		
General use	E	E
FOOD		
General Use	E	E
Breweries	E	E
Dairies	E	E
MISCELLANEOUS INDUSTRIES		
Plating	E	E
Petroleum	G	F
Tanneries	E	E
Oil and soap	E	E
Water and sewer	E	E

RATINGS:

E—No attack.
G—Appreciably no attack.
F—Some attack but usable in some instances.
P—Attacked—not recommended.
N—Badly attacked.
C—Cold—70° F.
H—Hot—150° F.

No. 11

(IN A SERIES ON CORROSION RESISTANT MATERIALS)

NEWS SECTION

A. I. Ch. E. WILL CEREBRATE AND CELEBRATE IN CHICAGO

BROAD aspects of chemical engineering will be a predominant theme for the September meeting of the A.I.Ch.E. Chicago will play host to the chemical engineers, along with thousands of others from various engineering societies, all of whom will meet during the month of September in a centennial celebration.

While the chemical engineers will get under way on Thursday morning, Sept. 11 instead of the usual Monday beginning, other engineering societies will hold meetings prior to and after the A.I.Ch.E. This is all part of a huge celebration—the Centennial of Engineering in the United States. Actually it commemorates the founding of the Civil Engineering Society, and the event will take place during the period Sept. 3-13, 1952. During that time 60,000 engineers are expected to make Chicago their headquarters.

As far as the A.I.Ch.E.'s part in the program, one of the broad survey meetings will be headed by Francis J. Curtis, vice-president of Monsanto Chemical Co. The symposium headed by Curtis, and titled "Chemical Industries," will be held on Monday, Sept. 9, and will be a part of a general engineering convocation. It will present papers on specific industries and economic conditions throughout the whole country. The program as of now, calls for papers to be given by the following:

S. D. Kirkpatrick, vice-president, McGraw-Hill Book Co.—*Definition—Importance of Chemical Industries*; W. K. Lewis, Massachusetts Institute of Technology—*Chemical Engineering—A New Science*; William T. Nichols, vice-president, A.I.Ch.E. and director of general engineering, Monsanto Chemical Co.—*Industrial Chemicals—Inorganic*; H. E. Thompson, vice-president, Union Carbide—*Industrial Chemicals—Organic*; Randolph T. Major, vice-president, Merck & Co., Inc.—*Drugs and Medicines*; Eger V. Murphree, president, Standard Oil Development Co.—*Petroleum*; F. C. McGrew, assistant research director, Du Pont Co., Inc.—*Plastics*; J. B. Quig, manager, textile research division, Du Pont Co., Inc.—*Fibers*.

The technical program of the A.I.Ch.E. has been under the supervision of Donald A. Dahlstrom, assistant professor, chemical engineering, The Technological Institute, Northwestern University. All day Thursday will be devoted to a symposium arranged to illustrate the contributions of the Chicago area to chemical engineering.

The Symposium will be held in the famous Red Lacquer Room which will seat 900 people. Co-chairmen of the morning session will be Paul D. V. Manning, vice-president of International Mineral and Chemical Co., and Harry McCormack, technical editor of Putman Publishing Co. Afternoon chairmen will be William E. Brinker, assistant chief engineer at Corn Products Refining Co., and Leroy F. Stutzman, professor at Northwestern Technological Institute.

Besides the regular general sessions, a symposium on Monobed Ion Exchange will be given on Friday morning and a symposium on Distribution of Chemicals on Saturday morning.

One outstanding paper to be given is "The Fluidized Solids Technique in the Petroleum Industry," by Robert C. Gunness, assistant general manager of manufacturing, Standard Oil Company of Indiana. Applications to catalytic cracking, hydrocarbon synthesis, oxidation reactions, and hydroforming will be discussed.

Several other papers will be presented on fluidization during the general sessions.

Complete details of the technical program plus extensive information on the entertainment aspects of the meeting, will be given in the August issue of "C.E.P."

Centennial Preparations

Already fifty-one engineering organizations have scheduled meetings in addition to the symposia programs, and thirty-nine of them will hold technical sessions during the convocation of the Centennial of Engineering. An account of the coming event which coincides with the anniversary of the founding of the American Society of Civil Engineers was printed in "C.E.P." January issue, page 35. It was recently announced that the program will give to engineering and to the general public a series of twelve symposia or major subjects. Each will be conducted by an eminent chairman and the main speakers will be experts in their respective fields. Papers will be presented in language understandable to the laymen.

(*Continued on page* 18)

Above is the Fine Arts Building, including the Museum of Science and Industry, where engineering developments of the past 100 years will be on exhibit during the Centennial of Engineering in Chicago.

NEWS

(*Continued from page 17*)

Also included are a reception for foreign delegates Sept. 3 and significant ceremonies on Sept. 10 which is designated as Centennial Day. The latter will include a special luncheon and an all-inclusive evening party.

Opportunities for sightseeing and entertainment will be provided by Chicago and numerous tours are being arranged. These will be indicated, in considerable detail, in the Official Centennial Program, which is intended to be a clear, simple and helpful guide; it is now in preparation by the staff of the Centennial Corp.

As one of the principal features of the Centennial of Engineering, a musical show titled, "Adam to Atom," is scheduled to play in the air-conditioned main theatre of the Museum of Science and Industry two and three performances daily throughout the summer season. This extravaganza will portray dramatically the panorama of mankind's advance by the utilization of engineering and scientific achievements.

The Centennial will have two major projects in addition to the musical dramatization. These are a convocation of leading American and foreign engineering societies and a new exposition in the Museum of Science and Industry, now being constructed, will explain engineering developments of the past 100 years.

A. E. C. ESTABLISHES INDUS. DEV. OFFICE

A new Office of Industrial Development headed by William Lee Davidson was established at the Washington headquarters of the Atomic Energy Commission May 1.

M. W. Boyer, A.E.C. general manager, said the purpose of the new office is to aid in the administration of the industrial participation program involving studies of power generation, and to expand the areas in which all types of industry may find an interest in the national atomic energy program. He added that Dr. Davidson's office will provide a point of contact with positive responsibility to foster wider industrial participation in the Commission's program and the development, as may be possible, of a more normal competitive approach to the problems and potentials of the atomic energy business.

Boyer stated further that the immediate importance of the new office is the support of the present defense effort.

Dr. Davidson was formerly director of physical research for the B. F. Goodrich Co., Akron, Ohio. Before joining Goodrich he was with Monsanto Chemical Co.

COMBUSTION'S PHYSICAL ASPECTS AT SYMPOSIUM

Plans for the 1952 International Symposium on Combustion, to be held at the Massachusetts Institute of Technology from Sept. 1 to 5, have been completed. The Symposium is open to all who are interested in combustion.

The last combustion symposium was held in 1948, and much new knowledge will be presented in some 100 papers from Great Britain, France, Holland, Belgium, Germany and Japan as well as from the research laboratories and educational institutions of the United States. At least fifty foreign experts in the field will attend.

Papers are now being reviewed by a papers subcommittee of the General Symposium Committee of sixty-eight American and twelve foreign members. Emphasis is being placed on the physical aspects of combustion, particularly wave phenomena and turbulence, treated from both experimental and theoretical standpoints.

Typical fields in which papers will be presented are ignition; stabilization in laminar and turbulent flow; limits of inflammability and detonability; instability phenomena; microstructure of combustion waves; theory of flame propagation; flame-jet structures; and combustion processes in rocket systems.

In addition to these fields, plans have been made for several survey papers and round-table discussions on special topics.

The complete papers will appear later in a single volume, similar to that issued after the 1948 Symposium.

All facilities of the Institute will be open to registrants for the symposium and living accommodations will be available in M.I.T.'s Alfred E. Burton House to those who specifically request reservations in advance.

Requests for registration forms or for further information on the symposium should be addressed to Summer Session Office, Attn: Combustion Symposium Committee, Massachusetts Institute of Technology, Cambridge 39, Mass., or to Prof. Hoyt C. Hottel, professor of fuel engineering at M.I.T. and Co-Chairman of the Symposium.

DOW REGISTERS FOR 100 MILLION ISSUE

The Dow Chemical Co. filed late last month with the Securities and Exchange Commission a registration statement covering a proposed public offering of $100,000,000 of convertible subordinate debentures. The debentures will be convertible into common stock of the company. The offering will be underwritten by a nationwide group headed by Smith, Barney & Co.

GERMANS COMPETE WITH U. S. ENGINEERS

"Aggressive leadership in engineering" by the United States is essential at the present time, according to E. W. Forker, head of the Blaw-Knox chemical plants division, who recently returned from a survey of technical achievement in Europe. He found that European, especially German, competition in many chemical-process industries is seriously threatening America's lead.

Of particular interest to chemical engineers is Germany's development of such process equipment and processes as recovery of phenol from coke-oven effluent, fatty-acid distillation, a new method of purifying gas, new techniques for salvaging waste pickle liquors, coal gasification, and a continuous process for deodorizing vegetable oils. "The recovery of German industry has been spectacular," said Mr. Forker after attending a chemical exposition sponsored by German process-equipment manufacturers, which, he said, "rivaled our own Exposition of Chemical Industries . . . in size and variety of equipment displayed."

The value of constructive competition for world markets was acknowledged by Mr. Forker, who also suggested the benefits to be derived from an exchange of technological advances. Three contracts for the construction of oxygen plants embodying German processes, one of the plants to have a daily capacity of more than 300 tons, have recently been placed by firms in the United States, where great interest has been aroused in the Linde Eismaschinen development of low-temperature processes for producing tonnage and high-purity oxygen and for separating all types of industrial gases.

WORLD'S LARGEST HOUDRIFLOW FOR TEXAS

The world's largest Houdriflow unit will be installed soon by Texas City Refining, Inc., at its Texas City (Tex.) refinery, according to an announcement of C. G. Kirkbride, president of Houdry Process Corp.

The new unit will crack heavy stocks and will have a design capacity of 19,000 bbl. a day. The new catalytic operation will supplant an existing 10,000-bbl. a day Houdry fixed-bed catalytic cracker constructed during World War II. The new installation will also incorporate a visbreaker in the catalytic circuit to provide additional charge stocks to the catalytic unit from heavy fuel oil. Completion of the unit is scheduled for the last quarter of 1952.

(*More News on page 20*)

L. W. Hull, F. J. Stokes Machine Co., Southampton, Pa. H. J. Kandiner, Allied Chemical & Dye Corp., Philadelphia, Pa. H. S. Wood, Mid-Continent Petrol Corp., Tulsa, Okla. Eldon M. Sutphin, Gulf Research & Dev. Co., Verona, Pa.

Wheaton Kraft, The Lummus Co., New York.

FRENCH LICK MEETING

More candid photographs of V.I.P.'s at the French Lick meeting. See June issue for the meeting story and other portraits.

▲ D. H. Killeffer, National Research Corp., Tuckahoe, N. Y.

L. A. Bromley, Univ. of California, Berkeley, Calif. ▼

R. G. Folsom, Univ. of California, Berkeley, Calif. E. L. Piret, Univ. of Minnesota, St. Paul, Minn. ►

▲ On their way to technical session.

F. W. Evans, and R. F. Zimmerman, Hooker Electrochemical Co., Niagara Falls, N. Y. ►

AROSORB PLANT FOR SUN OIL CO.

M. Robert Lipkin, section chief on special problems at Sun's chemical research lab., turns over the first spadeful of earth at the ground-breaking at Sun Oil's Marcus Hook refinery for a plant employing the company's newly developed Arosorb Process. Looking on, left to right, are: J. Bennett Hill, director of chemical research; Alfred E. Hirschler, senior research chemist; Stewart S. Kurtz, Jr., manager of chemical research (Norwood); and John R. Bates, director in charge of research and development. "C.E.P." published an article on the Arosorb process last month on p. 276 of the Engineering Section.

FELLOWSHIP IN CHEM. ENG. AT IOWA CITY

The division of chemical engineering, State University of Iowa, has announced that the Archer-Daniels-Midland Co., Minneapolis, Minn., has established a graduate fellowship in chemical engineering to begin with the 1952-53 school year.

The initial fellowship has been awarded to Francis B. McDaniel, Newton, Iowa, to begin his graduate study at the University in the fall.

The Archer-Daniels-Midland Co. is a large processor of agricultural crops.

The graduate fellowship which the company has established at the University of Iowa will carry a cash award of $1,900 for each full year of graduate study in chemical engineering. The fellowship is granted through the chemical engineering division and will be supervised by Dr. Karl Kammermeyer, professor of chemical engineering.

NEW ANILINE PLANT OF NATIONAL ANILINE

The National Aniline division of Allied Chemical & Dye Corp. proposes to build a new chemical plant for manufacture of nitrobenzene and aniline by newly developed continuous processes on a site south of Moundsville, W. Va. The site is adjacent to a new plant of the Solvay Process Division now in the course of construction which will manufacture chlorine and caustic soda using local salt deposits. The new catalytic process for aniline will use hydrogen generated in the Solvay operation.

Construction of National's new plant will start at an early date with completion projected in 1953; work will be directed by the division's engineering manager, F. J. Krueger. The Defense Production Administration has awarded Certificate of Necessity covering 60 per cent of the cost of the facilities estimated to exceed $2,300,000.

ADDITIONS TO STAFF AT KNOXVILLE

University of Tennessee, Knoxville, has announced additions to the staff in the department of chemical engineering.

Anton de S. Brasunas has joined the staff as assistant professor of metallurgical engineering. Dr. Brasunas had worked previously at the Battelle Memorial Institute and for the last two years has been a research metallurgist with the Oak Ridge National Laboratory.

Robert Kieber has joined the faculty with the title of assistant professor of chemical engineering and bacteriology. Dr. Kieber had worked previously with the National Aniline Co. and has recently been doing research for the Camp Detrick laboratories of the U. S. Army.

GLOBAL GROUP FOR CELANESE CORP.

Celanese Corporation of America has established a new global organization known as Celanese Central, S.A. to provide closer liaison with the activities of foreign affiliates of the company in all countries except Canada. Kenneth G. Donald has been named president of the new organization.

"During the past few years the size and scope of the activities of Celanese Corporation of America have substantially expanded," the company said. "Interests in other countries have become so large and diverse that a continuing liaison with these countries is needed, particularly at this time when the difficulties of foreign trade are becoming more pronounced.

"Obviously, there should not be any dilution of existing management while the corporation assumes broader proportions. We believe the answer to the problem is the establishment of an organization such as Celanese Central S. A., the activities of which will extend to all countries outside of the United States except Canada. In the latter country we have already established Canadian Chemical and Cellulose Company, Ltd., for the operation of the Canadian activities."

Foreign affiliates of Celanese Corporation of America, other than those in Canada, are as follows: Celanese Mexicana, S.A., Viscosa Mexicana, S.A., Celulosa Nacional, S.A., Claracel, S.A., all in Mexico; Celanese Colombiana, S.A. in Colombia, and Celanese Venezolana, S.A. in Venezuela.

SAFETY KUDOS TO OHIO-APEX & ATLAS

The first Lammot Du Pont safety plaque awards have been won by Ohio-Apex, Inc., of Nitro, W. Va., and Atlas Powder Co., Wilmington, Del., Charles S. Munson, chairman of the board of the Manufacturing Chemists' Association, Inc., recently announced.

Atlas Powder Co. had the best showing among chemical manufacturers with more than two million man-hours exposure. Seven plants of Atlas operated through 1951 without a lost-time accident.

Ohio-Apex, a division of Food Machinery & Chemical Corp., was the winner in the category of firms with less than two million man-hours exposure.

The plaques are awarded for the greatest improvement in accident frequency rate for the preceding two-year period in comparison with the rate for the three-year period immediately before that. In announcing the winners, Mr. Munson remarked as follows:

The chemical industry is a safe place to work. For 1950 the average accident frequency rate for reporting companies was 4.83 compared to 14.70 for all U. S. industry. For the first quarter of 1952, companies scored a further improvement with a rate of 4.03.

(*More News on page* 26)

clarify wastes at least cost...

the Cyclator®

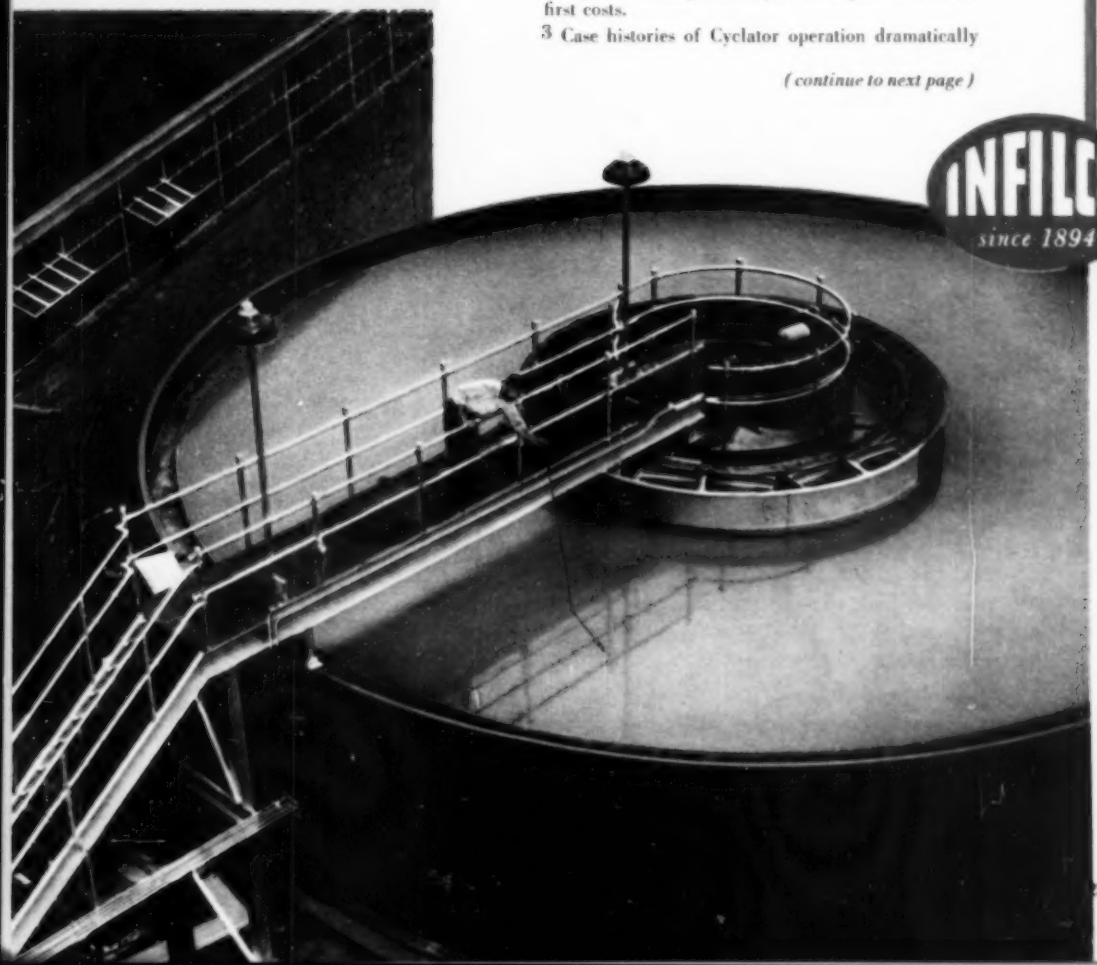
meets disposal requirements best...

1 Because the Cyclator combines recirculation for more complete clarification and faster settling with mechanical thickening for maximum sludge compaction... you gain greatest B.O.D., oil and suspended solids reduction at considerably higher flow rates than in "old style" disposal plants.

2 Because the Cyclator increases purification rates and eliminates the need for large chemical mixing, coagulating and settling basins, you save space... save on first costs.

3 Case histories of Cyclator operation dramatically

(continue to next page)



INFILCO
since 1894

(continued from preceding page)

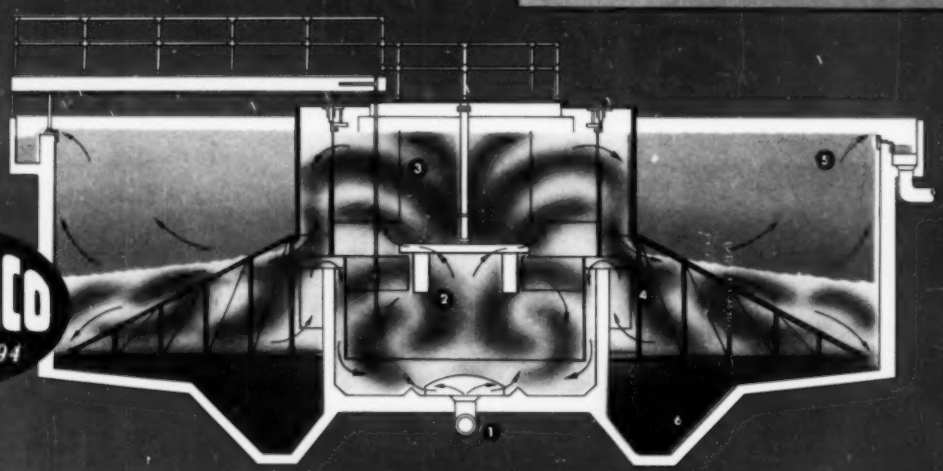
illustrate the vital point that the Cyclator will clarify wastes to your local requirements at least cost. Write for Bulletin 850A — containing data and case histories which show how the Cyclator exceeds expectations for processors everywhere — North America, South America, Europe.

INFILCO INC. ★ *Tucson, Arizona*

Here's how the Cyclator EXCEEDS waste disposal requirements

- ★ Space-savings up to 80% in comparison to "old-style" treatment plants.
- ★ By-product recovery and water re-use pay for Cyclator operation in many cases.
- ★ Removes suspended and colloidal solids, oils and toxic compounds rapidly and efficiently.
- ★ Throughput is extremely high because chemical feeding, recirculation and mechanical thickening are perfectly balanced in a single basin.
- ★ Reduces chemical costs because most efficient mixing is attained with recirculation.
- ★ Effluent purified to the degree required to meet pollution control regulations.

INFILCO since 1894



"EXPLAIN-MORE" DIAGRAM

1. Inlet
2. Mixing & Coagulating Zone
3. Circulating Zone
4. Settling Zone
5. Clarified Liquid
6. Sludge Sump

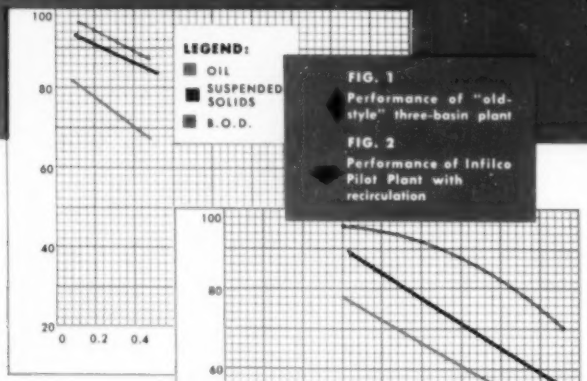
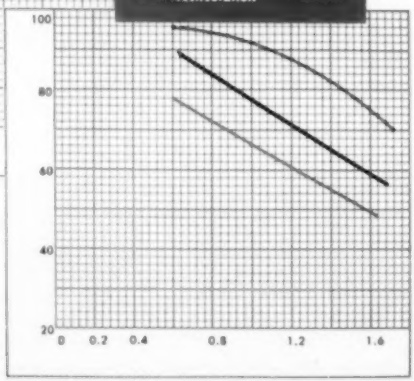


FIG. 1
Performance of "old-style" three-basin plant

FIG. 2
Performance of Infilco Pilot Plant with recirculation

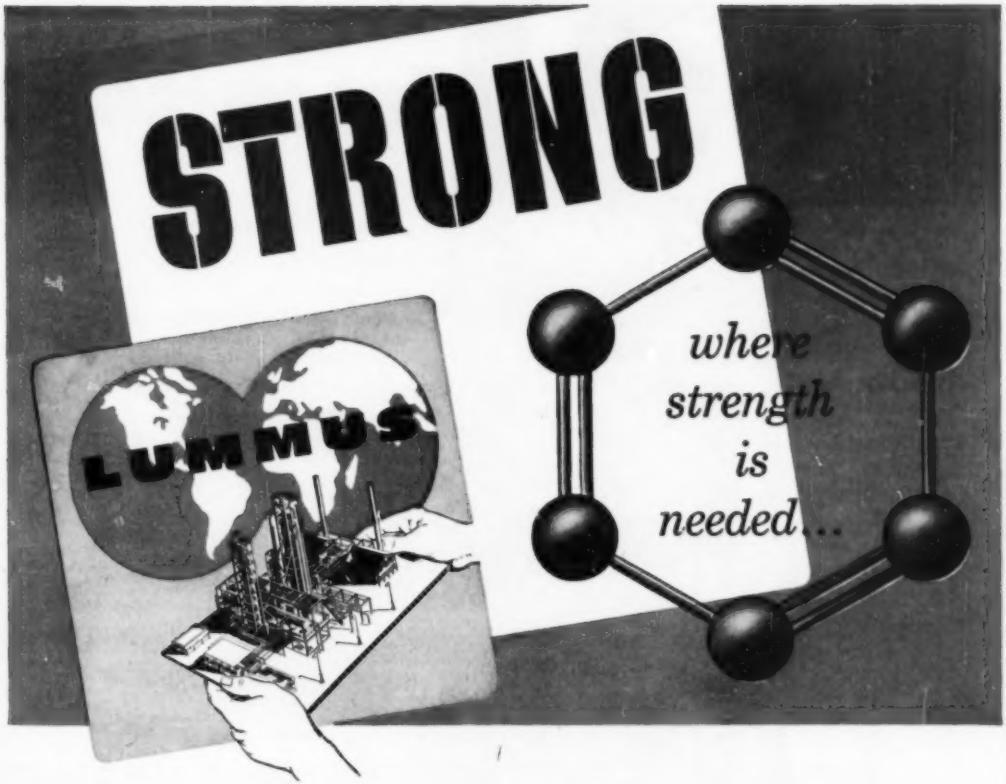


TAKE A LOOK AT PROCESS SAVINGS—

Here's a recent pilot plant study. An Infilco pilot plant was installed in parallel with a treatment plant with separate mixing, flocculating and sedimentation basins.

Both plants treated oil-bearing wastes. Alum and activated silica were used as the coagulants. Figure 1 shows that the three-basin plant operated at a rise rate of only 0.2 gpm per square foot for about 95% oil removal. Slightly higher removal was gained with the Infilco plant and at a rise rate of 0.6 gpm!

The result: two 100-foot diameter Cyclators were installed by a large Eastern refinery to treat waste at 3700 gpm. Process savings like this are typical of Cyclator installations. When you need facts for waste disposal at least cost, ask for Infilco's specialized experience . . . there's no obligation for preliminary planning.



The Lummus Company has played an integral and important role in the unfolding story of chemical progress.

Evidence? You'll find it all over the globe in the form of chemical processing units designed, engineered and constructed by The Lummus Company—plants whose initial run met or exceeded design capacity and never relaxed in performance.

Examples? Lummus has designed and built nearly 350 chemical processing units, included among which are plants for producing phenol, resins, solvents, asphalts, alcohol, acetone, toluol, ammonium picrate, and for manufacturing catalysts. We were at the forefront in providing huge styrene and butadiene plants to feed the vast synthetic rubber program. In providing ethylene manufacturing facilities, the name Lummus looms biggest of all.

May we suggest our symbol as a good one to look for, believe in, and rely on in connection with your next chemical processing project? You'll find us to be a group with the depth of chemical engineering talent and the breadth of experience to tackle engineering and construction problems anywhere in the world.

THE LUMMUS COMPANY

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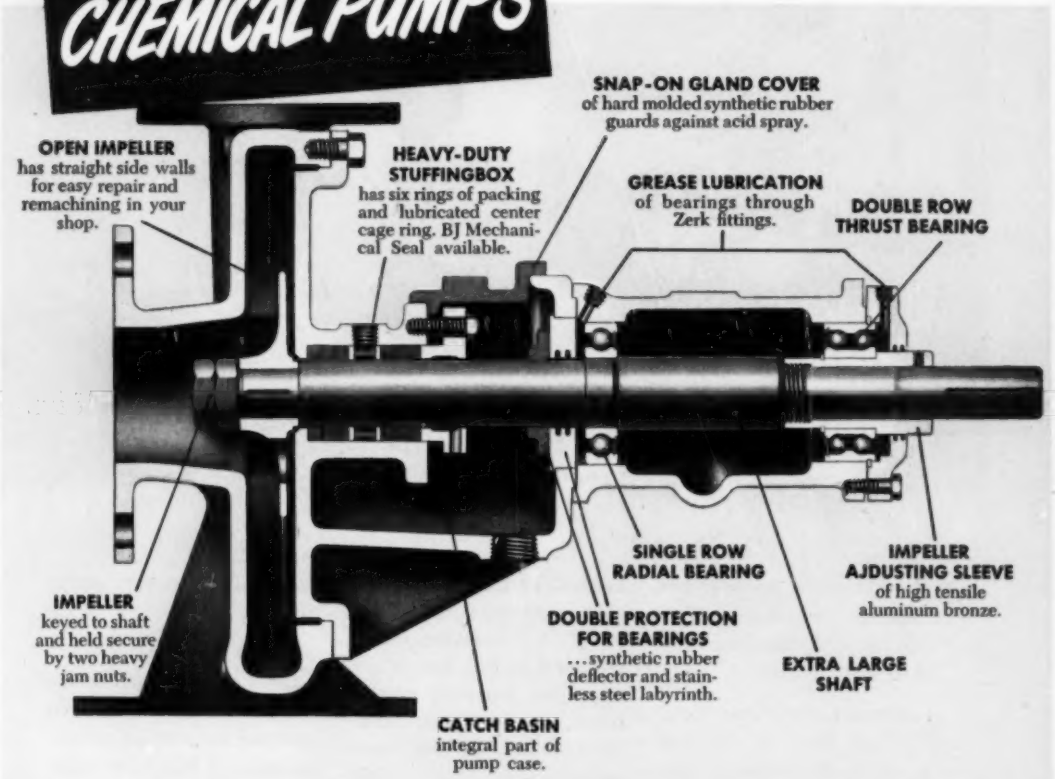
DESIGNING ENGINEERS AND CONSTRUCTORS FOR THE PETROLEUM AND CHEMICAL INDUSTRIES

NEW BJ CHEMICAL PUMPS

Here are chemical


SNAP-ON GLAND COVER
of hard molded synthetic rubber guards against acid spray.
OPEN IMPELLER
has straight side walls for easy repair and remachining in your shop.
HEAVY-DUTY STUFFINGBOX
has six rings of packing and lubricated center cage ring. BJ Mechanical Seal available.
GREASE LUBRICATION
of bearings through Zerk fittings.
DOUBLE ROW THRUST BEARING
SINGLE ROW RADIAL BEARING
IMPELLER AJDUSTING SLEEVE
of high tensile aluminum bronze.
IMPELLER
keyed to shaft and held secure by two heavy jam nuts.
DOUBLE PROTECTION FOR BEARINGS
...synthetic rubber deflector and stainless steel labyrinth.
EXTRA LARGE SHAFT
CATCH BASIN
integral part of pump case.

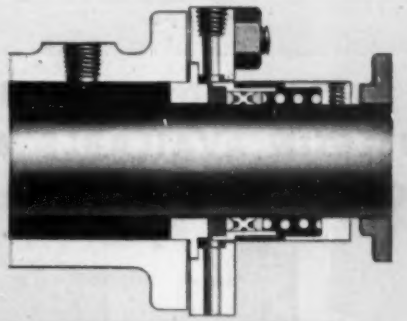
You've asked for them... now BJ introduces these special construction features!

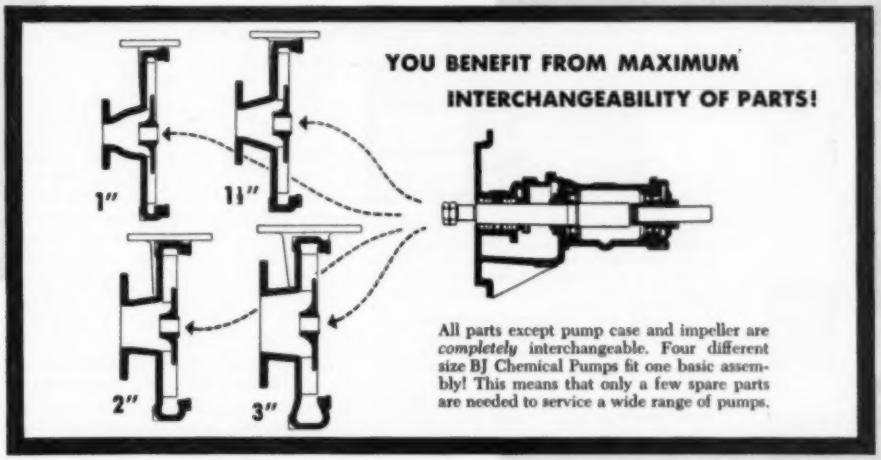
- *Quick and easy dismantling* for inspection and repair without disturbing piping or driver.
- *All parts interchangeable* except pump case and impeller. Four different pump sizes can be used on one basic stuffingbox and bearing bracket assembly.
- *Corrosion-resistant catch basin*—integral part of pump case—guards bearing bracket and base plate from corrosive leakage.
- *Adjusting sleeve* permits compensation for impeller wear—allows easy adjustment without dismantling.
- *Grease lubrication* gives bearings greater protection against acid fumes. Deflector and labyrinth provide double protection against liquid entrance.
- *Cored passages* through impeller web keep stuffingbox under suction pressure.

pumps engineered to your demands...

You—the chemical pump user—dictated the design of these new BJ Chemical Pumps. Before Byron Jackson engineered these new BJ models, chemical pump users were asked what features were wanted most. Now these improved features are yours in the new BJ Chemical Pumps. Four pump sizes are available (1", 1½", 2" and 3") with capacities to 450 gpm and heads to 100 feet.

BJ Mechanical Seal also available for protection against leakage. BJ's Type "A" Mechanical Seal is designed especially for the particular demands of chemical pumping. It replaces the packing and provides positive protection against leakage to the bearings or contamination of the pumped liquid. All major parts of this BJ-designed seal are effectively isolated from contact with pumped liquid. Available as special construction, the BJ Mechanical Seal will save you maintenance time and money by eliminating frequent repacking.





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All parts except pump case and impeller are *completely* interchangeable. Four different size BJ Chemical Pumps fit one basic assembly! This means that only a few spare parts are needed to service a wide range of pumps.

FOR MORE INFORMATION on these new pumps, write BJ Chemical Pump Dept. 4.

BJ makes a complete line of centrifugal pumps to answer your other pumping needs.

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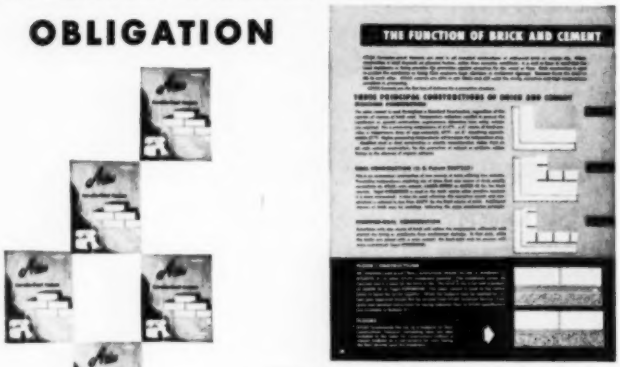
OFFICES IN PRINCIPAL CITIES

. . . a practical guide to Corrosion-proof cements

NEW, INFORMATIVE BULLETIN AVAILABLE WITHOUT OBLIGATION



HERE in concise form you will find complete data on the basic types of corrosion-proof cements and constructions. Each cement is graphically shown in its relationship to temperature and the broad classes of corrosives handled.

In addition, RESISTANCE TABLES are included which cover 176 common corrosives, and relate them to cements satisfactory for that service. And, ESTIMATING TABLES guide you in figuring not only cement, but also brick requirements for most corrosion-proof construction jobs.

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ATLAS PRODUCTS STAND . . . between your process and corrosion.

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NEWS

(*Continued from page 20*)

UNITED STATES LAGS IN I. S. O.

The necessity for dominant leadership in international standardization on the part of the United States was stressed by Roger E. Gay, president of the American Standards Association, at the second general assembly of the International Organization for Standardization in New York last month.

Standardization is an essential tool in welding the nations of the world in mutual understanding and consequently in increasing productivity, trade, and general harmony, and the United States, as a world leader in technology and industry, should be actively urging standardization, but instead, said Mr. Gay, "is following behind the enlightened leadership of other nations."

Of the eleven current recommendations for international standardization, among which are temperature reference, periodical-title abbreviations, twist direction of yarns, diffuse transmission density, and method for determining photographic speed and exposure index, only two were sponsored by the United States. This failure to act, according to Mr. Gay, is costing America the good will of other nations, who see this attitude as indifference; however it is due in part to "our method of developing standards, [which] . . . is slow but is an essential part of the democratic processes of our country." American participation in the I.S.O., he clarified, is through the A.S.A., which presents not its own views on any single standard but the combined agreement of all the manufacturers, technicians, etc., of the industry concerned, and such agreement is necessarily slow in forthcoming. Progress, however, has been made since World War II, and American industry is becoming aware of its responsibility toward international standardization.

The place of the I.S.O. in improving international relations was also discussed by Dr. Albert Caquot, president of the I.S.O. from 1949 to 1952, and by Willard Thorpe, Assistant Secretary of State for Economic Affairs.

MICROBIOLOGY JOURNAL TO APPEAR IN JANUARY

Applied Microbiology is the title of a new journal to begin publication in January, 1953, under the auspices of the Society of American Bacteriologists. It will appear bimonthly and the subscription price will be $7.50.

The magazine will deal with the applications of microbiology to industry, foods, sanitation, in fact all aspects except the microbiology of animal and plant disease. The Williams & Wilkins Co., of Baltimore, Md., will be the publishers.

NEW CHLOROPHYLL PLANT

J. C. Hearn, president of National Alfalfa Dehydrating & Milling Co., Lamar, Col., announced last month that Vulcan engineering division of The Vulcan Copper & Supply Co., Cincinnati, will design and construct a million-dollar chlorophyll plant for scheduled completion in the second quarter of 1953. The chlorophyll will be obtained from alfalfa meal by solvent extraction using the Kennedy continuous countercurrent extraction system. The plant will include facilities for the processing of the crude extract to produce finished chlorophyll suitable for industrial, pharmaceutical and medicinal purposes.

A new company, The National Chlorophyll & Chemical Co., has been organized to conduct the chlorophyll production activities originated by National Alfalfa. The new plant will be built beside the existing chlorophyll production plant in Lamar and will add 4000 lb. of chlorophyll a month to the production capacity.

HYATT AWARD FOR MELAMINE DEVELOPMENT

Palmer W. Griffith, West Coast technical service director of American Cyanamid Co., received the eleventh annual John Wesley Hyatt Award "for achievement of wide importance to the plastics industry," at the award banquet held at the Hotel Pierre in New York on June 5. He was cited for his researches with melamine bringing this material from a laboratory curiosity to a plastic which has become the basis of a new industry. The award consists of a gold medal and $1000.

The Hon. Dan A. Kimball, Secretary of the Navy, made the principal address. A distinguished group of leaders in the fields of plastics, chemistry, manufacturing and finance, witnessed the presentation by Gordon Brown, president, Society of the Plastics Industry.

ORGANIC CHEMICALS PLANT OF CARBIDE

Construction on a new multimillion-dollar plant for the manufacture of synthetic organic chemicals and plastic resins, about eight miles northwest of Seadrift (Calhoun County, Tex.) is being planned by Carbide and Carbon Chemicals Co., a division of Union Carbide and Carbon Corp. A Certificate of Necessity for this plant has just been granted in Washington by the Defense Production Administration.

Brown and Root, Inc., of Houston, will perform the design and construction on the new plant. Field work is scheduled to begin early this fall.

The new plant will produce a variety of organic chemicals and plastic resins.

(More News on next page)

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INDISPENSABLE TO INDUSTRY AND AGRICULTURE

PAPER FROM BAGASSE FOR CHILE

Successful commercial utilization of bagasse, the fibrous residue of sugar cane, to make paper was announced by W. R. Grace & Co., last month. The process has been in operation for some twelve years at Paramonga, Peru, and the Grace plant, on a 14,000-acre plantation, produces about 19,000 tons of all types of paper a year. A modified soda process is used. Above: as the bagasse leaves the sugar-grinding mill, a worker bales it for drying.

STAINLESS STEEL TUBING COUPLING

A new stainless steel fitting, designed for rapid coupling of lighter-wall stainless steel tubing, has been developed by Peter A. Frasse and Co., Inc., and the Cooper Alloy Foundry Co. Trademarked Quikupl, the chief advantage claimed for the new fitting is that it can join tube or pipe without threading, flaring, soldering, brazing, or welding. The new assembly, according to the developers, will permit use of less expensive stainless steel tubing and will reduce assembly costs.

In using the fitting, pipe or tubing is simply cut to length, deburred, and inserted in the fitting and the joint is completed merely by tightening a small screw. The piping is tightened by the screw and is held by a synthetic sealing ring which is contained in a groove machined into the bore of the fitting. The seal is constructed so that it will provide and maintain a squeeze fit, and pressure in the line from either direction, seals the space between the ring and the tube.

The new fitting will have a widespread application in the chemical processing, textile processing, photographic and oil refining industries, it is felt. At present the fitting is being manufactured in tees, couplings, ells and adapters in types 304 and 316 stainless.

As of present, the sealing ring is made of a special-type neoprene and can be used at temperatures up to 275° F. depending upon the corrosive agent involved.

The fittings are of the 150 lb./sq.in. class.

For more information use Data Service item No. 49.

BAKELITE FILM AVAILABLE TO PUBLIC

A new 16-mm. sound picture in color, "Flight to the Future," produced by the Bakelite Co., a division of Union Carbide and Carbon Corp., to answer such queries from the public as "Why Use Plastics?" will be released for national distribution to the general public Sept. 1, 1952. From July 21 to Sept. 1, the film will be available to personnel and organizations of the plastics industry only.

Inquiries should be made to Modern Talking Picture Service, Inc., 45 Rockefeller Plaza, New York, the national distribution agency which will do all the physical handling and booking of the film under contract with Bakelite.

CENTENNIAL AT MICHIGAN TO BE OBSERVED

Plans are under way for a centennial celebration of the inauguration of engineering courses at the University of Michigan.

A convocation on Oct. 23 and 24 of 1953 will mark the opening of the centennial program. George Granger Brown, dean of the College of Engineering, has appointed a faculty committee, headed by Prof. Stephen S. Attwood, to complete arrangements, aided by a five-member alumni advisory group.

When the University was moved from Detroit and re-established in Ann Arbor in 1837, engineering was one of the subjects the Regents believed should be offered. It was not until 1853, however, that any action was taken to name a faculty member to teach civil engineering.

At their meeting of Nov. 16, 1853, the Regents decided that Alexander Winchell, then in Alabama, was the faculty member they wanted. Negotiations with him were completed and he arrived on campus early in 1854. A course in civil engineering was inaugurated when the next term began on March 31, 1854. Engineering courses were continued as a part of the literary college until 1895, when a separate College of Engineering was established.

A.E.C. RELEASES ISOTOPE SUMMARY

The Atomic Energy Commission has made available a five-year summary of the isotope distributed from installations of the Commission. It shows that more than 10,000 radioactive isotopes and 2,000 stable isotopes have been distributed to users in the United States and 750 isotopes have been distributed to users outside of the United States. The book is available from the Superintendent of Documents at the Government Printing Office, Washington 25, D. C., for $1.00.

The book itself is primarily documentary evidence of the extensiveness of the isotope program. A short textual introduction covers the increase in the number of isotope shipments, the production and processing, isotope-labeled compounds, isotope procurement, and allocation, training, and the future of the program.

The tables, which constitute the bulk of the book, list the institution, state and department, the investigator, the isotope, the purpose of the study and the reference or status of the study. Then, there is an extensive bibliography broken down into topical headings. This lists some 1,400 studies on isotope utilization. The book also has an author index.

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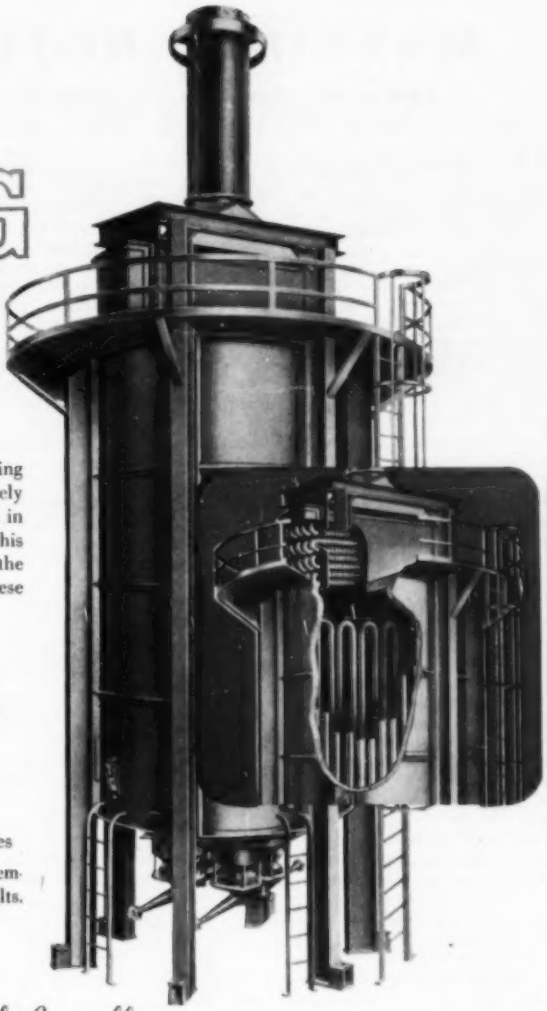
FIRED HEATING EQUIPMENT

for Dowtherm and Other Fluids



The Struthers Wells forced circulation system utilizing Dowtherm as a heat transfer medium has been widely accepted by the chemical industry and other users in recent years. Scores of large installations in this country, and numerous units abroad, testify to the universal satisfaction of the user. Many of these installations are repeat orders.

This system offers the user:

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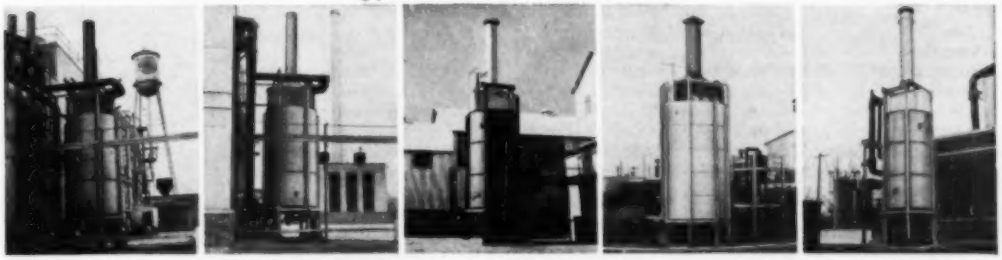
We also supply equipment for heating gases to high temperatures—for superheating steam—heating asphalts, absorption oil and a wide range of services.

Good deliveries are available in standard sizes.

Typical Installations



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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

A Time-Saver for Practician

Industrial Heat Transfer. F. W. Hutchinson. The Industrial Press, New York. (1952) x + 326 pp. $6.00.

Reviewed by V. J. Berry, Res. Eng., Stanolind Oil and Gas Co., Tulsa, Okla.

THIS most recent contribution to the heat-transfer literature represents a satisfactory solution to the problem of providing the practicing engineer with information upon which to base equipment design. Chapter headings include conduction, radiation, natural convection, forced convection, and combined heat transfer. Following the few pages of text at the beginning of each chapter are many graphs, each of which may be used for the direct graphical solution of one of the equations appearing in the text. Facing each graph is a page of description and discussion including one numerical example indicating the use of the graph. The author has virtually eliminated the necessity for any numerical calculations on the part of the user of the book by providing graphs for the determination of everything from log mean areas to film coefficients for the heating or cooling of isopropyl alcohol flowing inside a pipe.

The charts presented in the chapters on conduction, radiation, and combined heat transfer represent, for the most part, the solutions of such simple problems as the determination of heat loss given the thermal conductivity, area, and temperature difference. However, there are several charts new to the reviewer for the determination of shape factors in radiation problems.

The most effective selling point of the book, however, is the large collection of graphs included in the chapter on forced convection. These graphs represent solutions of the standard equations for the film coefficients for fluids heating and cooling, both inside and outside tubes. Separate graphical solutions have been constructed for each of 28 gases and 43 liquids of industrial importance. These 71 graphical solutions alone will make the book a valuable addition to the library of the practicing engineer.

There are several features of the book which may draw criticism. In particular, there are no detailed references concerning the sources of the data on fluid properties which were employed in the construction of many of the graphs. The accuracy of the graphs is not high, but it is claimed that their accuracy is equivalent to that of the correlations which they represent. Although in some places the notation is poor, for the most part it follows the standard chemical engineering nomenclature. There is no detailed development of theory nor discussion of experiment, and for this reason, the book is not recommended as a text, although it may serve in the capacity of a handbook. Discussion of the Schmidt method for graphical solution of unsteady state conduction is unsurpassed in its lack of clarity.

In spite of its shortcomings, however, the general utility of the book in day-to-day design calculations cannot be underestimated. It is well suited for use by anyone concerned with conventional heat-transfer design problems. The practicing engineer should find that the small investment in the price of this book will be returned many-fold in the form of time saved.

For the Instructor

Thermodynamics. Fourth Edition. Alfred W. Porter. John Wiley & Sons, Inc., New York (1951) 124 pp. $1.50.

Reviewed by G. E. Hays, Phillips Petroleum Co., Bartlesville, Okla.

PORTER'S book on thermodynamics, first published in 1931, aims to provide the reader an outline to understand the logical foundations of the subject of thermodynamics. In general, details of applications of thermodynamic principles have been left to larger texts. Porter's text is unique in that he presents the mental gymnastics of early contributors to the field of thermodynamics during their evolution of thermodynamic relationships, by discussing the sequence of reasoning of Carnot, Clapeyron, Kelvin, Clausius, and others. Because of his unusual approach, the book is of value to the instructor in thermodynamics. In this connection, however, it is noted that no verbal definition of entropy is offered other than that ". . . a reversible adiabatic is also an *isentropic* or line of constant entropy . . . ." Porter has divided his little book into five chapters: I. Introductory; II. Reversible Changes; III. Miscellaneous Applications; IV. Irreversible Operations, and V. On Equilibrium. Prof. W. Wilson has written (for this edition) Appendix I, Commentary on Porter's Thermodynamics, and Appendix II, Black Body Radiation. The latter appendix extends the text beyond Porter's writings. The book is one of the series "Methuen's Monographs on Physical Subjects."

Scattered Lubrication Data Concentrated

The Performance of Lubricating Oils. H. H. Zuidema. ACS Monograph 113. Reinhold Publishing Corp., New York (1952) 179 + viii pp. $5.00.

Reviewed by V. A. Kalichevsky, Consulting Chemical Engineer, Magnolia Petroleum Co., Beaumont, Tex.

THIS book fills a gap in the existing literature for a critical and comprehensive survey of the principles controlling performance of lubricating oils in service. The subject matter is well classified and presented in a readable form without burdensome details.

The book is divided into eight chapters: I. Process of Lubrication; II. Rheology; III. Oxidation; IV. Bearing Corrosion; V. Sludge and Lacquer Deposition; VI. Emulsification and Foaming; VII. Wear, and VIII. Manufacturing Methods. The last chapter is intended for readers who are unfamiliar with the general methods of manufacturing lubricants.

Up to the present time the information presented in the book was available in the form of articles or specialized treatise on the individual subjects. These scattered data were of little assistance to the students not intimately connected with the specific problems associated with the lubricating-oil performance. The book should be, therefore, of much value to technical persons both within and outside the petroleum industry who would like to increase the scope of their knowledge without unnecessary expenditure of effort in the study of sometimes contradictory details. It should be also of considerable assistance to all those who specialize in the lubrication problems by presenting the subject in its entirety while providing selected references for further studies of the individual items. The author is to be congratulated on handling this difficult and often controversial subject in a clear and concise manner.

The Oilmen. Text by Charles Parker. Photographs by Thomas Hollyman. Rinehart & Co., Inc., New York. (1952) 96 pp. $1.50.

HERE are 200 photographs which tell the story of men and women who find oil, get it out of the ground, move it to refineries and distribute more than 1000 products. The story behind the book started a year ago and was made possible by the cooperation of the employees of Shell Oil Co. These arresting pictures cover every phase of the oilmen's work "from the oil fields in California and the swamplands of Louisiana to the service station in Connecticut."

(*More Marginal Notes on page 32*)

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"KARBATE" TOWERS do more than retard corrosion – they eliminate it *entirely* from such processing operations as absorption, fractionation, evaporation, extraction, scrubbing, and many others. Furthermore, the widespread acceptance of impervious graphite for all types of corrosion-free process construction has resulted in the manufacture of monolithic tower sections and fittings in sizes to 24" I.D.

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- **STRENGTH AND EASE OF INSTALLATION**
- **SIMPLICITY OF FABRICATION AND MODIFICATION IN THE FIELD**
- **HIGH HEAT CONDUCTIVITY**
- **RESISTANCE TO CORROSION AND THERMAL SHOCK**
- **NON-CONTAMINATION**

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MARGINAL NOTES

(*Continued from page 30*)

Shaping to Specifications

Extrusion of Plastics, Rubber and Metals. Herbert H. Simonds, Archie J. Weith, and William Schack. Reinhold Publishing Corp., New York. (1952) 454 pp. $10.00.

Reviewed by E. R. Riegel, Prof. Ind. Chemistry, Buffalo, N. Y.

THIS work is a treatise on the industry which bears the same name, and which has expanded at a phenomenal rate. Extrusion molding is vis-à-vis injection molding, over which it has the commanding advantage of being a continuous process, while injection molding is a discontinuous one. In this treatise there are presented: equipment, process, and materials. Also, "the unusual versatility of the extrusion machine as an industrial unit is described for the first time. . . . Methods of molding, compounding, pelletizing and packaging form a significant part of the book," quoting from the foreword by C. Wm. Cleworth, publisher of "Plastics World." The authors had the benefit of an Advisory Committee of ten experienced practicing engineers in plastics industries, with James Bailey as chairman.

The book is divided into three parts of unequal lengths. Part I, "Extrusion of Plastics," covers 306 pages. Part II, "Extrusion of Rubber, Metals and Miscellaneous Materials," covers 72 pages. An appendix requires 57 pages, and the index the balance. In the appendix there are included a glossary, a list of manufacturers of extrusion products, and a list of manufacturers of extrusion equipment in the United States and Canada. This review will concern itself mainly with Part I.

Extrusion, as said before, is a continuous process; its aim is to produce a continuous specifically shaped product to relatively close dimensional tolerances. A chapter is devoted to the design and use of dies. Means for overcoming the formation of bubbles in the extrusion of acrylic resins are described.

The text includes numerous graphs and illustrations. Chapter 7, on "Theoretical Aspects," develops the formula of Rogowski which relates the pressure to the rate of extrusion in cubic units, the screw diameter, and the viscosity of the material at the die temperature. Other formulas, by Bailey, permit the determination of the proper volume per pitch of the screw. The discussion includes many references to equipment and practice in the United Kingdom.

Part II contains the "Extrusion of Rubber," "Extrusion of Metals," and the "Extrusion of Miscellaneous Materials," such as graphite electrodes, carbon for lead pencils, ice, catalysts, wood waste, glass.

The make-up is attractive. However, it would serve the convenience of the reader if the right-hand running-heads included the chapter number.

"Extrusion . . ." is a valuable aid to the engineer studying or practicing extrusion. For the non-specialist, the book offers interesting information in a not-well-known field.

For the Engineer and Plastics Man

Plastics Molding. John Delmonte. John Wiley & Sons, Inc., New York. (1952) 493 pp. + vii. $9.00.

Reviewed by Richard J. Francis, Consulting Engineer, Newark, Ohio.

THIS book considers the problems involved in converting organic plastics materials into useful industrial and consumer products. A prime problem facing these converters (molders) is the application of heat and pressure to plastics materials. These are tools familiar to the chemical engineer, and they are given a lucid, engineering treatment.

An introductory chapter makes the distinction between thermosetting and thermoplastic resins and discusses their flow characteristics under applied heat and pressure. Individual chapters treat compression and transfer-molding equipment, injection-molding equipment and extrusion equipment. Dies for plastics are described in two other chapters.

The remaining ten chapters cover hydraulic pumps and accumulators, packings, valves, fluid flow, heat from vapor, liquid and electrical sources, material preparatory equipment, finishing accessories and plant lay-out, and while these supplementary chapters are directed to an audience of plastics men, they should be helpful to engineers in other fields.

Included in the discussion of mechanical pressure systems are toggle, worm and gear, and rack and pinion mechanisms. Under special molding conditions, springs provide follow-through pressure to compensate for material compacting.

While chemical engineers likely will be familiar with the discussion of fluid flow, they may benefit from the discussion of some of the newer pumps and valves and their performance characteristics.

As its name implies, the book is concerned with plastics molding, and the subject is not confused with a discussion of resin formulation. Laminating of flat sheets is not covered, and except for a brief mention of preforming, the molding of fibrous glass reinforced plastics is not covered.

Minerals and Nature

The Formation of Mineral Deposits. Alan M. Bateman. John Wiley & Sons, Inc., New York. (1951 xi + 371 pp. $5.50.

Reviewed by Paul D. V. Manning, Vice-Pres., Res. Div., International Minerals & Chemical Corp., Chicago, Ill.

AUTHOR Alan M. Bateman, Silliman Professor of economic geology at Yale University, consulting geologist to Kennecott Copper Corp. and editor of Economic Geology, has summarized much of the available knowledge as to how mineral substances happen naturally. He states that he has written for the purpose of answering this question for "the scientist, the engineer, the industrialist, the layman and the student." In the reviewer's opinion, the author has succeeded very well.

Introducing this study by showing the importance of mineral deposits in shaping world affairs and history, he stresses that the rapid present consumption of previously discovered mineral reserves makes imperative, the discovery of new sources. It is important for the layman to learn that by definition, the term *ore* is used to describe raw material from which metals only may be extracted with profit. It is also important to understand that mineral deposits are the results of natural concentrating processes which operated subsequent to the formation of the earth.

One important feature of the book is the selection of references which follows each chapter. A list of general references, the geological timetable and a glossary are given at the end of the volume. Ample illustrations and tables of data are found throughout the work.

In covering his subject, the author includes chapters on mineralizing solutions, igneous activities, magmatic, contact-metasomatic and hydrothermal processes. Also given are chapters on the processes of sedimentation, weathering, metamorphism and the effect of ground water.

Factors which control minerals, the localization of mineral deposits and methods of exploration and mining are briefly but well covered.

The last chapter is devoted to a short but good summary of the mineral resources of the world.

The Everlasting Bug

Insect Control by Chemicals. A. W. A. Brown. John Wiley & Sons, Inc., New York. (1951) 817 pp. $12.50.

Reviewed by R. W. McNamee, Supt., Res. and Dev. Carbide and Carbon Chemicals Co., South Charleston 3, W. Va.

A GREAT deal of scientific information and practical art relating to

control of insect pests by the use of chemicals has been assembled in this book. The organization of material is excellent. The net result is a book which should be useful and interesting to practical entomologists, students, farmers, chemists, toxicologists, and even to laymen who have a fair preparation in chemistry.

This text presents a clear, orderly treatment of the chemical control of insects and the methods and equipment for their dispersal. It provides the essentials of insect toxicology, with particular emphasis on modern organic insecticides and is documented by source references.

The author has classified the insecticides in present-day use and gives their chemical and physical properties. Three chapters are devoted to a discussion of the relationship of the structure of organic compounds to insect toxicity and to the susceptibility of insects to these materials. The classes of insects rather than the crops they affect form the divisions under which the insecticides are discussed. The equipment in current use for the ground and airplane applications of insecticides are illustrated and the physical factors influencing the dispersal of these materials are covered.

Several chapters are devoted to the toxicity of insecticides to mammals and to plants and to the precautionary measures which should be observed in handling these chemicals. The last chapter is devoted to a discussion on the effect of insecticides, particularly DDT, on the balance of nature.

Chemical formulas of nicotine, parathion, and ethyl *p*-nitrophenylthionobenzenephosphonate are incorrect. For the reason that much of the subject matter is more or less topical it will probably be revised frequently, making it possible to eliminate such minor errors.

Books Received

The Conduction of Electricity Through Gases. K. G. Emeléus. Methuen & Co., Ltd., London. John Wiley & Sons, Inc., New York. Third edition revised. (1951) 99 pp. $1.50.

Proceedings of the Fourth Annual Conference on Administration of Research, University of Michigan, Ann Arbor, Mich. (1950) 100 pp. $3.00.

The Welding of Non-Ferous Metals. E. G. West. John Wiley & Sons, Inc., New York (1952). 553 pp. $8.50.

Light Hydrocarbon Analysis. Edited by O. W. Burke, Jr., C. E. Starr, Jr., and F. D. Tuemmler. Reinhold Publishing Corp., New York (1951). 639 pp. $15.

Quantitative Chemical Analysis. Charles W. Foulk, Harvey V. Moyer, and William M. MacNevin. McGraw-Hill Book Co., Inc., New York. (1952) ix + 484 pp. $5.00.

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Which Means

- lower pressure drop
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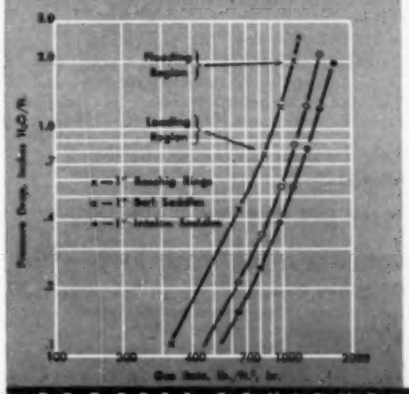
- higher flow capacities

TABLE ONE

Comparative Properties of Intalox

	Raschig Rings	Intalox	Berl Saddles
Nominal Size	1"	1"	1"
Approx. No./ft³	1350	2390	2200
Approx. Wt./ft³	40	39	45
Aver. Surface area ft²/ft³	58	78	76
% Free Gas Space	73	74	69

TABLE TWO



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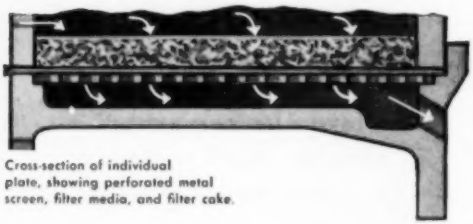

Cross-section of individual plate, showing perforated metal screen, filter media, and filter cake.

High flow rates cannot be assured by large filtering surfaces *alone*. Another important factor is provision for drain-off space capable of carrying away all liquid that the surfaces can handle.

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NEW DATA SERIES ON PLASTICS

With this issue "C.E.P." begins publication of a series of reference sheets on the corrosion resistance of plastic materials. The data will cover the essential qualities of practical interest to chemical engineers and we hope will serve as an easy reference guide for our readers with problems that may be solved by the use of plastics and plastic coatings. This series follows and supplements the Cast Alloy Reference Sheets (1-10), codified by N. S. Mott, chief chemist metallurgist of the Cooper Alloy Foundry Co., which began in July, 1951, and concluded with the June, 1952, issue.

Raymond Seymour, E. A. Erich and Robert Steiner, compilers of the new series, will arrange data on cements and equipment, and coatings and linings in the field of plastics. The first reference sheet (No. 11) can be found on page 374.

Dr. Seymour is executive vice-president and technical director of the Atlas Mineral Products Co. He was at one time associated with the Goodyear Tire & Rubber Co., Monsanto, and Johnson & Johnson. He holds numerous patents in the fields of materials of chemical construction, plastics, etc. Dr. Steiner is director of research of Atlas which he joined in 1950. Prior to that year he had been a research chemist at Firestone Tire & Rubber Co.

Mr. Erich is a graduate of Muhlenberg College with a B.S. in chemistry. Since graduation, he has been employed by Atlas, starting in the research laboratory and later being assigned to Technical Service which he now heads.

POLLUTION, SAFETY DATA SHEETS OF M.C.A.

A bibliography on air pollution, covering causes, effects, control and abatement methods, has been published as Chapter 12 of the M.C.A. Air Pollution Abatement Manual, according to a recent announcement of the Manufacturing Chemists' Association, Inc. Remittance of 50 cents for each copy of the chapter should accompany orders.

Other recent publications of M.C.A. are:

Chemical Safety Data Sheet SD-44 and SD-45, the first titled Chromic Acid Chromium Trioxide, and the second Ammonium Dichromate. These data sheets, available at 25 cents from M.C.A., cover the properties and essential information for the safe handling and use of these chemicals. Also announced is publication of a revised Manual Sheet TC-4 (20 cents) covering the unloading of flammable liquids from tank cars.

Each publication can be secured from the Manufacturing Chemists' Association, Inc., Woodward Building, 15th and H Streets, Washington, 5, D. C.

LETTER TO THE EDITOR

ENGINEERS IN SERVICE

Sir:

Many young engineers and chemists now in military service have the best intentions of maintaining their civilian status within their profession. These men are confronted with a difficult problem, the solution of which should be of vital interest to the companies with which the men are now or may eventually be affiliated. With these scientific fields advancing as rapidly as they are, it is imperative for the technical specialist to keep in constant contact with the professional advances or he ceases to live in the world of today. He no longer knows what work is to be done and what has been done.

The ways in which an engineer or chemist may make an effort to keep abreast of his profession are several. The means most effective is to remain in constant touch with his profession by being a member of a few of the existing professional societies. This requires only a nominal amount for the yearly dues, but one must attend a majority of the local meetings to derive a measurable benefit. These items, inexpensive as they are, are rather costly to one living on a soldier's pay.

Many periodicals are available to engineers and chemists for a nominal subscription fee, but, in general, must be procured by the individual rather than through his unit's library. This little item takes a substantial amount of the small pay of the serviceman.

Books are constantly being published containing a high grade of design data and ideas. These also have a monetary value and add to the plight of the young soldier-engineer.

The crowning touch handed to the young, aspiring engineer or chemist, currently in military service, is that the social requirements of an engineer are usually somewhat in excess of the average man in service. This means to hold his professional standing, he must dress and act the refined individual he is and is expected to be.

With the existing shortage of technically trained men, it is necessary for the men within the professions to remain in or attain the highest possible level. It would be to the advantage of industry as a whole to adopt a policy which would assist its technically trained men in their endeavors to maintain their professional standing during the time that these men spend in military service.

June 8, 1952

Herbert L. Watts, Pvt.
Arsenal, Ark.

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Chicago, Ill., Palmer House, Sept. 11-13, 1952.
Technical Program Chairman: D. A. Dahlstrom, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.
Technical Program Chairman: R. L. Savage, Dept. of Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.
Technical Program Chairman: Norman A. Spector, Vitro Corp., 233 Broadway, New York 7, N. Y.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.
Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michigan, Ann Arbor, Mich.

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16, 1953.
Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.
Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

SYMPOSIA

Distribution of Chemicals
Chairman: D. A. Dahlstrom, Northwestern University, Evanston, Ill.
Meeting—Chicago, Ill.

Monobed Ion Exchange
Chairman: F. J. Van Antwerpen, Editor, Chemical Engineering Progress, 120 East 41st St., New York 17, N. Y.
Meeting—Chicago, Ill.

Applied Thermodynamics
Chairman: W. C. Edmister, California Research Corp., Richmond, Calif.
Meeting—Cleveland, Ohio

Human Relations
Chairman: R. L. Demmerle, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Cleveland, Ohio.

Modern Statistical Methods in Chemical Engineering
Chairman: C. Daniel, Engineering Statistician, 116 Pinehurst Ave., New York 33, N. Y.
Meeting—Cleveland, Ohio.

Filtration
Chairman: F. M. Tiller, Dir., Div. of Eng., Lamar State College of Technology, Beaumont, Tex.
Meeting—Cleveland, Ohio

High Pressure
Chairman: E. W. Comings, Head, School of Chem. & Met. Eng., Purdue University, Lafayette, Ind.
Meeting—Cleveland, Ohio.

Mineral Engineering Techniques for Chemical Engineers
Chairman: N. Morash, Titanium Div., National Lead Co., P. O. Box 58, South Amboy, N. J.
Meeting—Biloxi, Miss.

Chemical Engineering in Hydrometallurgy
Chairman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.
Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.

Fluid Mechanics
Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Absorption
Chairman: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

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NEWS

(*Continued from page* 34)

U.P.A.D.I. MEETING IN NEW ORLEANS IN AUGUST

The second convention of UPADI (Pan American Union of Engineering Societies) will be held in New Orleans, La., Aug. 25-30, 1952. UPADI formed to provide a common meeting ground for Western Hemisphere engineers, a means to discuss mutual problems and an opportunity to exchange ideas and information, was formally constituted at a convention in Havana, Cuba, in April, 1951. A.I.Ch.E. takes part in its activities through E.J.C.

The second convention will consider further revisions in the Constitution and adopt a set of bylaws. A technical program will be held on Aug. 26. Its theme will be Engineering Education. The program is being developed by Leo Jos. Lassalle, dean, college of engineering, Louisiana State University. The Convention will meet at Tulane University. Air conditioned McAllister Auditorium will be the center of activities.

A.I.Ch.E. delegates are the following:

K. H. Kobe, chemical engineering dept., University of Texas, Austin 12, Tex.
W. D. Kohlins, Buflovak equipment div., Blaw-Knox Co., 295 Madison Avenue, New York, N. Y.
T. H. Chilton, Du Pont Co., 10498 Nemours Bldg., Wilmington, Del.
S. L. Tyler, Secretary, A.I.Ch.E., 120 East 41st Street, New York, N. Y.

PLACEMENT SERVICE FOR ENLISTED MEN

A placement committee was recently organized by the Enlisted Specialists Chemical Engineering Club at the Army Chemical Center, Maryland, to help soldier specialists that make up its membership establish contact with leading chemical and industrial companies. Hundreds of enlisted specialists assigned to the Chemical Center under the Army's Scientific and Professional Personnel program will be released soon.

These are now filling technical and professional jobs for the Army in capacities varying from chemical engineering research assistants to biological statisticians. Many of these soldiers will be seeking permanent places in outside industry. Thus the committee has been set up to help these men make contacts with civilian firms, and is inviting representatives of leading chemical and industrial companies to interview these enlisted men.

The Commanding General of the Army Chemical Center and of the Chemical Corps Research & Engineering Command, Brig. Gen. William M. Creasy, has pledged his support to this activity of the enlisted men.

TEACHERS LEARN INDUSTRIAL PRACTICES

EDITOR'S NOTE

This is an account of a one-day meeting for teachers of chemical engineering where the actual steps in the construction and operation of a contact sulfuric plant of Monsanto's in New England were demonstrated. This symposium follows in purpose the ideas contained in an article by Kenneth A. Kobe, printed in "C.E.P." September, 1951, page 48. Therein he discussed the industry-sponsored school for faculty members, with the motto, "Teach the Teachers."

THE first industrial symposium for teachers of chemical engineering in New England took place at the Merrimac plant of the Monsanto Chemical Co., May 10. Teachers from seven colleges and Monsanto representatives from several plants took part in the all-day session on the manufacture of sulfuric acid. The meeting was planned to make available to teachers information on industrial practice not available in the literature.

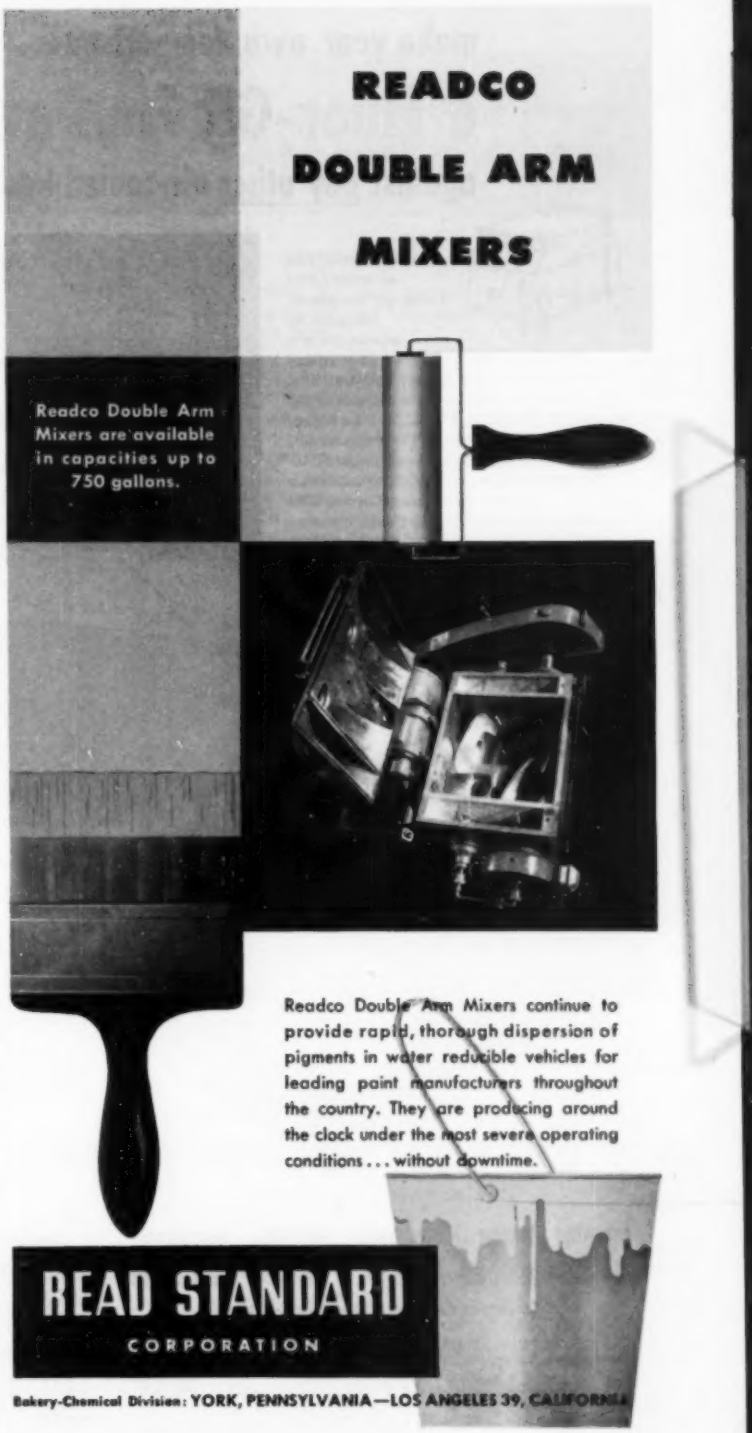
Prof. W. L. Kranich of Worcester Polytechnic Institute organized the symposium for the Chemical Engineering Education Projects Committee of the American Institute of Chemical Engineers. The program was planned and directed by G. J. Odom, assistant to the production manager at the Merrimac plant.

Technical Papers and a Tour

The program was designed to show the steps involved in the planning, design, construction and operation of a contact sulfuric acid plant with illustrations drawn from the Merrimac unit erected in 1949. Included in the program were papers discussing a market survey, general considerations and details of plant design, problems of construction and operation, theory of reaction, economics, handling and transportation, and a prediction of future developments. The two sessions of technical papers were separated by a tour of the plant under discussion.

Schools represented at the seminar included University of Massachusetts, Massachusetts Institute of Technology, University of New Hampshire, Northeastern University, Tufts College, Worcester Polytechnic Institute and Yale University. Total attendance including teachers and Monsanto representatives was 45.

Tentative plans were discussed for an industrial seminar in a different field to be sponsored by A.I.Ch.E. for chemical engineering teachers in New England in the spring of 1953.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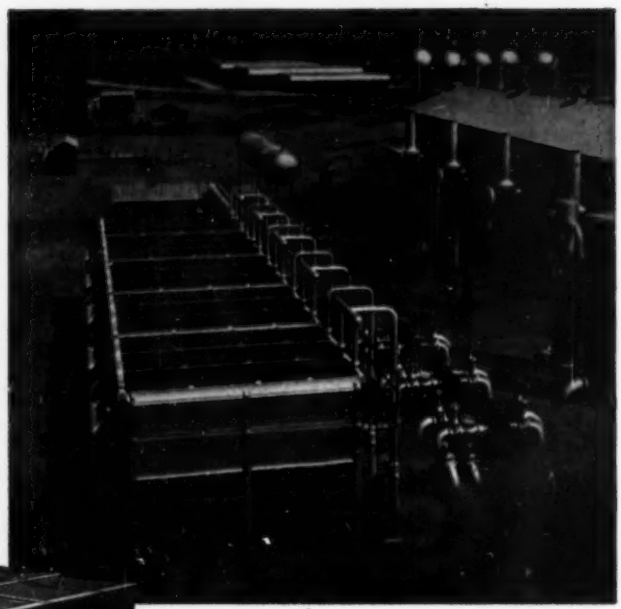

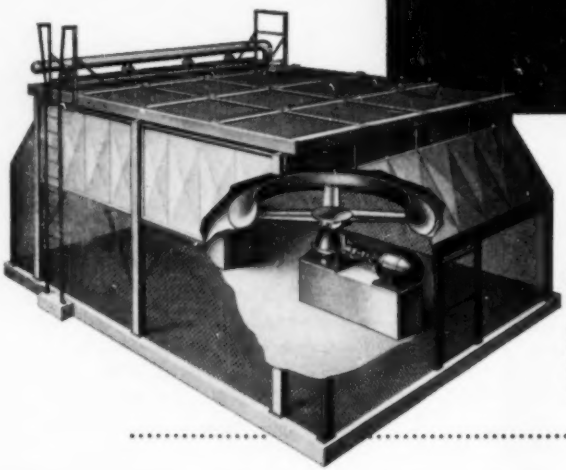

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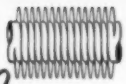

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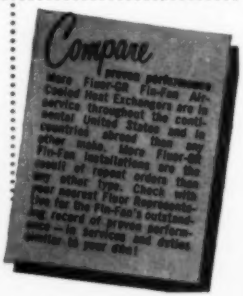
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Chemical Engineering Progress

DATA SERVICE

CHEMICALS

1 • HUMECTANT. The chemical division of Marathon Corp. has a new type of humectant composed principally of sodium lignosulfonate and modified carbohydrates. Source is wood. Dark-brown liquid containing 50 to 55% solids. pH of 8.5 to 9.5. Laboratory samples available.

2 • NEW SILICONE. General Electric's chemical division producing new sodium methyl siliconate. Major use potentially masonry water repellents, but also applicable to textiles, paper products, catalyst preparation, additives to silicates, etc. Can be dried to a white powder which can be redissolved.

3 • ACETYLENE COMPOUNDS. Air Reduction Chemical Co. four tertiary acetylenic alcohols and glycols. They are methyl butynol, methyl, pentynol, dimethyl hexynediol, dimethyl octynediol. New product data bulletin, physical properties, mechanical properties, reactions, references, etc.

4 • GLUCURONOLACTONE BOOKLET. Corn Products Refining Co., chemical division, booklet surveying all of the current literature available on glucuronolactone. Gives physical properties, analysis, clinical studies, abstracts of articles on the clinical use and references.

5 • RADIOACTIVE UREA. A urea C^{14} commercially made by Tracerlab, Inc. Useful for labeling compounds for biochemical use as well as preparation of plastics.

6 • ALDEHYDES. A bulletin from the Tennessee Eastman Co. on various aldehydes. Includes specifications and uses of acetaldehyde, *n*-butyraldehyde, crotonaldehyde, and isobutyraldehyde.

7 • ORGANIC CHEMICALS. Eastman Kodak Co. announced recently a group of ten compounds to their organic chemicals list. A listing of the various products is available from the company.

8 • VALVE SEAL. A silicone lubricant from Dow Corning Corp. for pressure-lubricated valves and flowmeter bearings operating at temperatures from −40 to 500° F. Has wide resistance to chemicals and gases. Nonmelting, does not gum, etc. Brochure lists physical properties of the valve seal, plus table listing the suitability in various inorganic, organic, and mixed chemicals, and gas processing.

9 • NITROCELLULOSE. A revised edition of the technical booklet about nitrocellulose from Hercules Powder Co. Data on nitrocellulose solubility, use in plasticizers and resins, applications, etc.

10 • CALCIUM CARBONATES IN PLASTICS. A reference bulletin by Diamond Alkali Co. on the use of precipitated calcium carbonates in reinforced plastics. Supersedes earlier editions. Covers two carbonates in fabricating reinforced polyester resins. Gives advantages, summarizes laboratory tests on the effects of loading on physical properties, flexural strength, tensile strength, compression, impact, and also on the chemical resistance.

11 • RUBBER ANTIOXIDANT. Styphen I (chemically, tris (a methylbenzyl) phenol mixture), used as an antioxidant for both GR-S and natural rubber, in production by the Dow Chemical Co. Nonstaining for producing white rubber products.

12 • ISOLATING ACETYL PEROXIDE. Buffalo Electro-Chemical Co. has issued a data sheet which describes a method for isolating acetyl peroxide. Hazardous to isolate heretofore, data sheet reports a safe way to isolate the substance by vaporization from a dimethyl phthalate solution.

BULLETINS

22 • PIPE ECONOMY. The title of a 300-page engineering reference book for engineers, buyers and users of all types of cast iron products for handling liquids, of James B. Clow & Sons. Too vast for complete description but gives dimensions, weights, constructions of pipes and pipe fittings, valves, traps, gratings, etc. Extensive number of pages on engineering data on flow, conversion factors, discharge, etc.

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Chemical Engineering Progress

DATA SERVICE

23 • *PERFORATED MATERIALS.* Catalog of The Harrington & King Perforating Co. on perforating service to industry. Covers the types of materials perforated, extensive section on types of perforating, and designs.

24 • *KILNS, COOLERS AND DRYERS.* Traylor Engineering & Manufacturing Co. bulletin on rotary kilns, coolers, and dryers. Well illustrated shows application to cement, lime, chemical and process plants of huge equipment. Gives information on operation, construction, etc.

25 • *SEWAGE AND TRASH PUMP.* Fairbanks, Morse & Co. describe a new bladeless pump for moving sewage and trash. Nonclogging-type featuring a bladeless impeller capable of handling fibrous trash. Vertical shaft and horizontal shaft pumps from 2- to 5-in. discharge. Shows construction, type of impeller, drive, modifications, dimensions, etc. For the chemical engineer with a problem in moving solids.

26 • *MIST ELIMINATORS.* A bulletin on mist eliminators made from corrosion-resistant metal wire knitted into a mesh and fabricated into sections to fit equipment. Bulletin shows the elimination of mist from a gas and describes application to petroleum towers, vacuum stills, packed towers, etc. Metal Textile Corp.

27 • *MILLS.* A bulletin from Daffin Mfg. Co. on mill units for grinding and pulverizing grains and other materials. Hammer type. Bulletin describes six units. Table gives specifications, construction details of each. Especially aimed at food processors and feed producers, but adaptable and being used in the chemical process field.

28 • *DEHYDRATORS.* Ardrier dehydrators from The Heil Co. Bulletin describes design features of complete systems. Originally intended for flash-drying of forage crops. Temperatures up to 1800° F., features rapid evaporation. Operated at 6000 lb./hr. on material with initial moisture content of 65%.

29 • *INDUSTRIAL TV.* For observing a scene or operation too dangerous, inaccessible, inconvenient, for direct viewing, R.C.A. has a special catalog supplement on industrial television equipment. Features only two units, a 10-in. viewing screen with remote optical focus and camera. Lists variety of uses for a number of industries.

30 • *METAL CRUSHER.* American Pulverizer Co.'s metal turning crusher for reducing metal turnings to chips. Crushers available from 50-200 hp. and capacities from 2½ to 10 tons/hr. of metal. The crusher gives faster handling of metal as well as making the product easier to briquet.

31 • *DOUBLE-FLOW AQUATOWERS.* A new Marley Co., Inc., double-flow cooling tower for intermediate cooling-water capacities. Features low silhouette fitting into current industrial designing of low, long buildings. Simple geometrical design of tower adapts to concealment by masonry, and double-flow method results in low pumping head, open distribution, complete air-water contact, and better maintenance and inspection.

32 • *FILTERS.* A bulletin on various types of filters from the process equipment division of General American Transportation Corp. Covers auxiliary equipment, fabricating facilities, rotary disc vacuum, rotary drum vacuum, rotary hopper vacuum dewaterer, rotary release pressure filter, sludge filters, solvent dewaxing filters, and how to select the type best suited for your purpose. Well illustrated, gives standard sizes, weights, dimensions, general materials of construction, etc.

33 • *MECHANICAL AIR SEPARATORS.* Single and double Whizzer separators for classifying materials already in powdered form, is described in a new bulletin by the Raymond Pulverizer Division. The device separates fine products from the coarse and delivers a finished material with controlled particle size. May be used in a closed circuit with a pulverizing unit or an open circuit receiving feed from hoppers, bins, screens, etc. Bulletin explains principles of operation, range of units, tables, specification sizes and dimensions, etc. In closed circuit the oversized particles are returned to mill for regrinding.

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DATA SERVICE

34 • RUBBER-LINED PIPE. A description of the Raybestos-Manhattan, Inc., rubber-lined pipe. Also fittings and valves. Bulletin explains how lining is adaptable to most types of pipe—wrought steel, wrought iron, flanged, cast iron, etc. Size limitation is 1 in. I.D. Rubber-lined valves available from ½ to 14 in. Also describes flexible rubber pipes. For use in chemical plants and process industries where corrosion and abrasion is a problem.

35 • SHEET FILTERS. For filtering practically any liquid in the chemical, food, pharmaceutical and other industries, Hercules Filter Corp. describes an industrial sheet filter in a new brochure. Has single spindle-type tightening device. Filter usually constructed of bronze but other metals available. End frames have been eliminated and can use any type of filter media. Four models available with filtering surfaces available from 350 sq. ft. down to 4½ sq. ft. Can be mounted on portable carriages for wheeling into autoclaves for sterilizing.

36 • THERMOCOUPLES. New catalog and data book from Wheelco Instruments Division which contains prices, applications, recommendations and pertinent information on thermocouples. An extensive book of information, it covers practically every type of thermocouple in existence, tells how to make thermocouples, how to use them., etc. Contains many pages of calibration data on thermocouple use.

37 • KJELDAHL UNITS. A brochure on the well-known Kjeldahl digestion and distillation units. Describes an apparatus with a flask capacity from 6 to 24 flasks with either gas or electric heat. For the control or analytical laboratory with job to do on protein materials. Laboratory Construction Co.

38 • FILTER FABRIC SELECTION. From Equipment Development Co., Inc., a brochure titled, "A New Slant on Filter Fabrics." Briefly it is a description of highly twisted yarn fabrics for use as filter fabrics. It explains why these fabrics work, discusses filtration as a whole and shows how the yarn construction helps for more efficient filtration.

39 • COOLING TOWERS. J. F. Pritchard & Co. equipment division new brochure on Cotospray cooling towers. Units are delivered prefabricated and can be erected by one man. Charts in bulletin give capacities and tons of refrigeration, dimensional specifications and man-hours for assembly of some eighteen different towers. Sample problems given to help determine sizes, type of cooling tower needed for specific applications.

40 • SCALE CATALOG. A 28-page condensed scale catalog from the Howe Scale Co. Handy reference showing a complete line of scales for industrial use. Includes a selection from a thousand scales and units displayed weigh from $\frac{1}{64}$ oz. to 400 tons. Not only covers industrial scales with automatic recording and controlling features but covers tank scales, fan-type counting-scales, postal scales, counter scales, sacking, hopper, floor, etc.

41 • FILTER PRESSES. An engineering data book on filtering from T. Shriver & Co., Inc. Covers advantages of filter presses, their selection, types of plates and frames, filter capacity, description of various discharges, washing of filter cake, plus charts on the approximate cost of cast iron plate and frame filter presses, cast iron recess plate filter presses and wood filter presses. Quite a complete compendium of filter information.

42 • SULFUR FIRES. To combat hazard of sulfur fires, Ansul Chemical Co. issued a new bulletin covering special extinguishers for purpose. Recommends dry chemical extinguishers.

43 • DIFFUSION PUMPS. Data sheets from Distillation Products Industries which describe and chart the characteristics of a m.c.f. diffusion pump. The pump is used for pressures less than 10^{-5} mm. Hg. Data sheet provides information on forevacuum, fractionation, speed, baffles, and in stallation.

44 • STEAM GENERATORS. A newly released bulletin by Clayton Mfg. Co. on self-contained steam generators. Either single or multiple units. Uses forced recirculation principle which bulletin demonstrates by charts and drawings. Operational data for industrial processes is given.

EQUIPMENT

49 • QUIKUPL. A stainless steel fitting for joining light-wall stainless tubing and pipe is announced jointly by Peter A. Frasse & Co., Inc., and Copper Alloy Foundry Co. The fittings have an internal groove machined into the bore into which is fitted a synthetic sealing ring. By inserting the tube into the fitting against a shoulder and turning a small screw inserted in a clamp which is an integral part of the fitting the seal is made complete. Now available as tees, couplings, ells and adapters in 304 and 316 stainless. Good up to 275° F. for 150 lb./sq.in. tubing. Engineering data and technical bulletin available.

50 • SARAN RUBBER. Description on use of Saran rubber for tank linings and other applications where corrosive problems are encountered available from Saran Lined Pipe Co. Contents include properties, comprehensive listings of the resistance of Saran rubber to chemicals and solvents, and illustrations of many current uses.

51 • PRESS CHARGER. For charging the plastic molding machines with an accurate amount of plastic, Glengarry Processes, Inc., have a new charging unit. Adjustable over a

range of ½ oz. up to 80 oz. the charger uses a supply hopper and electric vibratory feeder, a weigh bucket mounted on a beam, and a solenoid-operated gate on the weigh bucket. Uses net weight in its operation and entire cycle is synchronized with that of the molding machine.

52 • PICTOGRAPH. For the engineer or draftsman required to make numerous graphic charts Chart-Pak, Inc., has introduced a new series of pictographs on pressure-sensitive tapes. The tapes adhere to any material such as paper or cloth and are illustrated with standard statistical patterns of men, women, stacks of coins, bills, etc. Picture charts may be drawn simply by applying the tapes to the chart.

53 • VARIABLE-FLOW PINCHCOCK. Variable-flow pinchcocks for use in a laboratory or pilot plant to control gas or fluid flow in rubber and other flexible tubings. Fisher Scientific Co. Will fit tubings up to ⅜ in. in diameter. Made of Castaloy.

54 • DEHUMIDIFIER. Dryomatic Corp. manufacturing an absorption-type package dehumidifier for use in laboratories and plants. Affords humidity control to as low as 15% in areas up to 10,000 cu. ft. Operates from −40° F. to +100° F. The unit uses a combination of activated alumina and silica gel. Works in cycles, dries for 2½ hr., vaporizes the absorbed moisture for 30 min. all automatically.

55 • ELECTRICALLY HEATED VALVES. Okadee Co. announces electrically heated valves. Designed to keep valve mechanisms clear of frost and ice in liquid and carbon dioxide lines at temperatures as low as −110° F. Heated-valve sizes range from 2 to 6 in. with pneumatic, hydraulic, solenoid or manual control. Heating elements either 110- or 220-volt operations.

56 • DUST COLLECTOR FABRICS. For use in dry separation equipment and dust collectors, Filtration Engineers, Inc., announce two Orlon weaves. For use with hot and corrosive materials. Can be used at operating temperatures up to 300° F. and resist chemical attack by mineral acids, chlorine, oxidizing chemicals, etc.

57 • AUTOMATIC METER. A new Auto-Stop meter that automatically controls the quantity of industrial liquids fed into processes for batching operations is new with Neptune Meter Co. This is shown in a new catalog by the company which lists more than thirty different types of meters for industrial use. All are the positive-displacement type and the catalog shows meters ranging from 2 to a 1000 gal./min. with temperatures up to 250° F. and pressures up to 500 lb./sq.in. On Auto-Stop meter, the tripping mechanism is actuated by push buttons, and the meter, after being cleared, automatically stops at the indicated amount.

58 • TUFCLAD. Lapp Insulator Co., Inc., is now making a new line of chemical porcelain armored with fiberglass-reinforced plastic. Tradenamed Tufclad, the Lapp line includes valves, piping, and other equipment all protected by multiple layers of fiberglass woven cloth impregnated with a phenolic resin. Available on the complete Lapp standard line.

59 • HYDROTORQUE. A hydraulic positioning control system for high accuracy at remote distances has been announced by the Farris Hydrotorque Corp. For use in industrial, refinery and chemical fields, the device will automatically position valves, metering nozzles, etc. Will indicate level, flow, static pressure, temperature, etc., with only a calibration of dials to custom requirements.

60 • MINIATURE MODELS. Miniature indicators for liquid level and valve position, which occupy a minimum panelboard space, have been developed for the line of graphic panel instruments produced by Minneapolis-Honeywell Regulator Co. Indicators give the illusion of liquid level by using a colored metal tape behind the scale.

61 • BUTTERFLY VALVE. A pneumatically operated butterfly valve for control of air, water, or steam flow is new with Minneapolis-Honeywell Regulator Co. Operates on a controlled air pressure range to 15 lb./sq.in. Adjustable mechanical stops provided on the motor enable wing rotation to be limited for special applications. Size 1½ to 6 in., maximum operating temperature 250° F., maximum pressure 20 lb./sq.in.

62 • SPRAY NOZZLES. A new group of spray nozzles has been developed by Spraying Systems Co. For heavy-duty industrial applications, the line is of large capacities. Orifice diameters of better than 5 in. can pass solids as large as 2½ in. Capacity is 1550 gal./min. at 10 lb./sq.in.

63 • FLOW COLORIMETER. Beckman Instruments, Inc., have developed a flow colorimeter for analyzing and controlling flowing or static streams in liquid or gaseous processes. Uses light beams passing to a reference phototube and another passing through the flowing sample to a measuring phototube and comparing variations in light intensity. For maintaining continuous color control in beverages, electroplating, for monitoring gases, dyebath analysis, controlling bleaching solutions, etc.

64 • MOISTURE INSTRUMENT. An instrument for testing moisture content in nonmetallic dry granular material is new with Moisture Register Co. Electronic in operation, the unit includes a hydraulic press in which the sample is placed, compressed and a range box inserted at the base of the measuring cup. The moisture content is read on a microammeter located on the master measuring unit. Lightweight, portable, can be used either for production line testing or field checking of samples.

65 • AIR FILTER. Mine Safety Appliances Co. with a new Ultra-Aire space filter. Filters will remove 0.3μ. The unit comes in air flow sizes of 50, 500, and 1000 cu.ft./min.

66 • PRIMING INDUCTOR. For centrifugal pumps which do not have their own self-priming devices Nagle Pumps, Inc., have developed a priming inductor. For pumps situated above water level it is basically a water operated jack, its purpose being to fill the entrance pipe with liquid so as to initiate pumping. For use with horizontal shaft pumps. Made to fit entrance pipes from 1½ in. to 18 in.

67 • PORTABLE EMERGENCY SHOWERS. A line of mobile emergency showers for transfer or installation at point or points of hazardous operation is now being made by Logan Emergency Showers, Inc. Couplings for connection to water system on each unit. Showers are on rolling casters, has four overhead sprays, four bottom sprays directing water upward, and two special sprays for eyes and face. Entered from either side, valve is actuated by swinging gate. For use also in pilot plants where temporary processing equipment is installed.

The Answer to Your Centrifugal Problems can be found in this

Complete line of Sharples Continuous Centrifuges

NOZLJECTOR

Solids are continuously discharged from the disc type bowl of this high efficiency centrifuge which is widely used for separation of two immiscible liquids containing solids, or for the concentration of solids in a liquid phase.

to

- **SEPARATE TWO IMMISCIBLE LIQUIDS**
- **CLARIFY LIQUIDS**
- **REMOVE OR RECOVER SOLIDS FROM SLURRIES**
- **CONCENTRATE SOLIDS**
- **CLASSIFY SOLIDS BY PARTICLE SIZE**
- **DEHYDRATE OR RECOVER CRYSTALS**

SUPER CENTRIFUGE

Highest centrifugal force commercially available (13,200 x G) is developed by this tubular bowl continuous centrifuge. Easy to clean, it can be used to separate immiscible liquids with small differences in specific gravity or to effectively clarify liquids.

DV-2 CENTRIFUGE

Solids ranging from firm to slimes and sludges are handled by this versatile centrifuge, with continuous solids discharge. Available as a clarifier to remove solids from liquids; or a separator, to separate two immiscible liquids in the presence of solids.

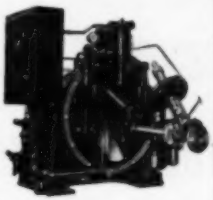
You Can Depend On Sharples— unbiased recommendation based on the most efficient centrifuge for your job.

D-2 CENTRIFUGE

This disc type, continuous centrifuge utilizes the stratification principle which is most effective in concentrating a liquid or solid phase suspended in another liquid.

SUPER-D-HYDRATOR

An extremely flexible, completely automatic centrifuge for recovery and dehydration of crystals. Efficiently handles slurries with 15 to 60% solids. Each step of feed, rinsing and drying can be individually controlled.



SUPER-D-CANTER

High capacity centrifuge for removal of solids from liquids . . . clarification of liquids . . classification of solids. Available in two bowl types to accommodate wide range of solids consistencies.

SHARPLES

THE SHARPLES CORPORATION • 2300 WESTMORELAND STREET, PHILADELPHIA 40, PENNA.

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Product temperatures up to 550°F. Far beyond the range of steam at corresponding pressure. Merrill Process pressures negligible as system is vented to the atmosphere. No danger from direct fire. No offensive odor. Thermostatic control keeps heating oil within a few degrees, high enough to do job without overheating batch.

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Versatile, Dependable, and Safe

Penstock Asphalt Coating

Versatile—may be used on product equipment that cannot stand pressure such as glass-lined vessels.

Dependable—just smooth, quiet, delivery of heat. Any quantity, any temperature. 35 years of sound, practical experience guarantees that.

Safe—all the time. Steel pumps, steel valves, steel fittings and accessories, extra heavy at that. Insurance companies like these features.

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Complete line of Jacketed Fittings too: Bulletin 152

Parks-Cramer Company

ENGINEERING, MANUFACTURING, AND INSTALLING

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Low Cost Protection for

HEAT EXCHANGER TUBE ENDS

In the past 31 years Conseco has provided millions of Flowrites for tube inlets of heat exchangers operating in all industries and all applications. Tube inlets become eroded and worn long before the remainder of the tube, and by reinforcing the inlets it is possible to increase the effective tube life many times.

Flowrites—made of the same metal as the tubes—are available in any length, diameter or gauge. They are easy to install and remove by unskilled help. When Flowrites themselves become worn (*instead* of the tubes!), just pull them out and install new, longer Flowrites.

Get the facts from the 8-page Flowrite "proof" booklet, available upon request.

CONDENSER SERVICE & ENGINEERING CO.

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before August 15, 1952, at the Office of the Secretary, A.I.Ch.E., 120 East 41st, New York 17.

APPLICANTS FOR ACTIVE MEMBERSHIP

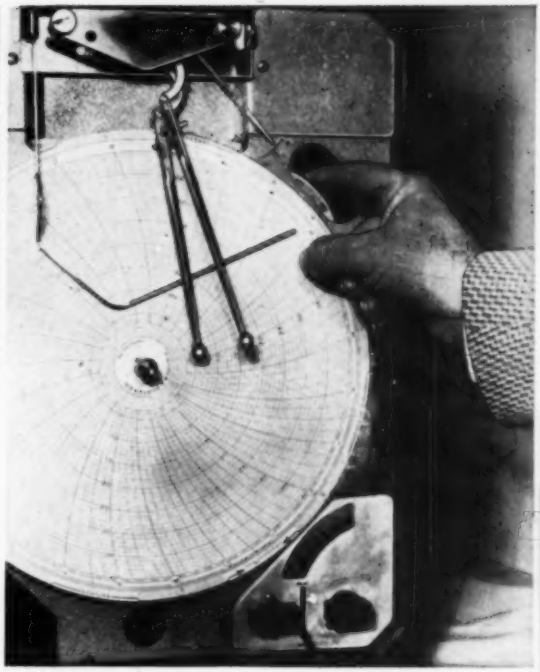
Allen, William H., *Trona, Calif.*
Armstrong, R. M., *West Chester, Pa.*
Bearry, E. C., *Hercules, Calif.*
Bedingfield, Charles H., Jr., *Claymont, Del.*
Bennett, Martin Toscan, *Washington, D. C.*
Bernath, Louis, *Schenectady, N. Y.*
Blohm, C. L., *Los Angeles, Calif.*
Bobalek, Edward G., *Cleveland, Ohio*
Bornwasser, Louis P., *Louisville, Ky.*
Butler, Wilburn J., *Houston, Tex.*
Buttrill, Carrol O., *Beaumont, Tex.*
Calder, John M., *New York, N. Y.*
Calise, V. J., *Long Beach, N. Y.*
Carpenter, James K., *Pittsburgh, Pa.*
Chastant, Waldo J., *Springhill, La.*
Clancy, J. J., *Westwood, Mass.*
Cline, Robert M., *Luckey, Ohio*
Codwise, Philip W., *Kenmore, N. Y.*
Colker, David A., *Phila., Pa.*
Curtis, L. A., *Lake Jackson, Tex.*
Dillon, Ira G., *Chicago, Ill.*
Dykstra, Robert A., *St. Louis, Mo.*
Edwards, George Griffith, *Amherst, Va.*
Eggimann, Ervon J. H., *Westfield, N. J.*
Garriga, Maurice, *Affton, Mo.*
Goughnour, A. A., *Charleston, W. Va.*
Hegedus, John B., *Charleston, W. Va.*
Higby, Floyd D., Jr., *Buenos Aires, Argentina*
Hopkins, H. S., *Charleston, W. Va.*
Horvath, Donald S., *Oreland, Pa.*
Huguet, J. H., *Baton Rouge, La.*
Hyslop, James M., *Niagara Falls, N. Y.*
Jonnard, A., *New York, N. Y.*
Keesling, Harold E., *Kingsport, Tenn.*
Les Veaux, John F., *Middleport, N. Y.*
Mahlberg, Roy F., *Niagara Falls, N. Y.*
Maurer, John J., Jr., *Corpus Christi, Tex.*
McKay, Neil H., Jr., *Houston, Tex.*
Miller, Wilbur A., *Dover, Del.*
Osterloh, Frederick V., *Freeport, Tex.*
Pierson, John E., *Charleston, W. Va.*
Raetzsch, Carl W., *Corpus Christi, Tex.*
Remsen, Irving B., *Pittsburgh, Pa.*
Rogers, Edgar A., *Chattanooga, Tenn.*
Ruhlen, Stafford L., *Penns Grove, N. J.*
Sapp, Alva C., *Elkton, Va.*
Schwabland, George A., *Alexandria, Va.*
Schwartz, Seymour, *Brooklyn, N. Y.*
Sharpe, G. V., *Charleston, W. Va.*
Shemilt, L. W., *Vancouver, B. C., Canada*
Slack, Charles N., *Charleston, W. Va.*
Smatko, Joseph S., *College Park, Md.*
Smith, John T., *Chicago, Ill.*
Smith, Michael K., *Charleston, W. Va.*
Thompson, C. E., *Newport, Del.*
Tymstra, Francis T., *Houston, Tex.*
Weaver, Morrison E., *Charleston, W. Va.*
Webber, Alfred R., *Avon Lake, Ohio*
White, John F., *Medford, Mass.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

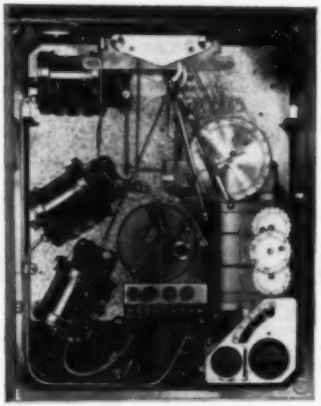
Boedeker, Edward R., *Marcus Hook, Pa.*
Cheesman, Willard L., *Peoria, Ill.*
Cheng, Jen Pu, *St. Louis, Mo.*
Clark, Kenneth A., *Richland, Wash.*
Davidson, Leon, *Arlington, Va.*

(*Continued on page 46*)

NEW
FISCHER & PORTER
automatic
FLOW RATIO CONTROLLER



Compact size with extreme precision of ratio control are important advances in this *new* Fischer & Porter Ratio Controller. Designed specifically for flow ratio control, it makes a perfect combination teamed with the new P-4 Pneumatrol and highly accurate Flowrator meters or variable area cell kinetic manometers, to assure accurate and dependable ratio control of fluids, gases or slurries. Receives pneumatic, electrical, or electronic primary signals. Review the features below, then mail the handy coupon for complete engineering and application data.



Interior view of standard Ratio Controller with pneumatic set ratio adjustment.

The compact stack mounting of the new Ratio Controller atop the P-4 Pneumatrol provides the simplest possible unit. The large (10½" scale) ratio setting dial permits precise ratio settings which are visible through the door. F&P wide range, linear scale primaries give extreme range of ratio (6:1 to 1:1 to 1:6; a total of 36:1).

CHECK THESE FEATURES:

- Extreme flexibility
- Wide range of ratio
- Based on linear scale primaries
- Control deviation indicator
- Primary element fully corrosion resistant
- Highly visible ratio setting dial
- Extremely compact stack mounting

1717

FLOWRATOR

FISCHER & PORTER COMPANY

170 COUNTY LINE ROAD, HATBORO, PENNA.

Please send me by return mail complete information on your new Ratio Controller.

NAME_____ POSITION_____

COMPANY_____

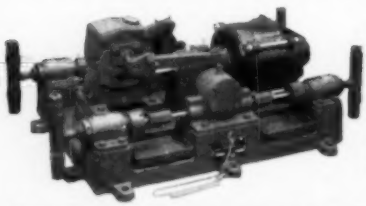
ADDRESS_____

CITY_____ ZONE____ STATE_____

Here's a handy guide to the selection of metering and proportioning pumps

In this new catalog and pump selection manual for Hills-McCanna "U" Type Metering and Proportioning Pumps is all the information, including prices, for the selection of exactly the right pump for handling over 300 substances. Clearly and concisely, this helpful booklet gives all the necessary information and specific recommendations to cover the vast majority of needs that can be filled with a Hills-McCanna "U" Type Pump.

If your operations involve the metering or proportioning of small volume flows, you will find this catalog a useful addition to your files. We will be pleased to send you a copy on request. HILLS-McCANNA COMPANY, 2438 W. Nelson St., Chicago 18, Illinois.



Hills-McCanna "U" Type Pumps are reciprocating, variable stroke, mechanical drive units with maximum capacities ranging from 0.10 to 24 gph. per feed. One, two, three and four feed assemblies are available. Operating pressures up to 5,000 psi. A four feed unit is shown at the left.

HILLS-McCANNA

metering and proportioning pumps

Also Manufacturers of: Saunders Patent Diaphragm Valves Force Feed Lubricators • Magnesium Alloy Sand Castings

CANDIDATES

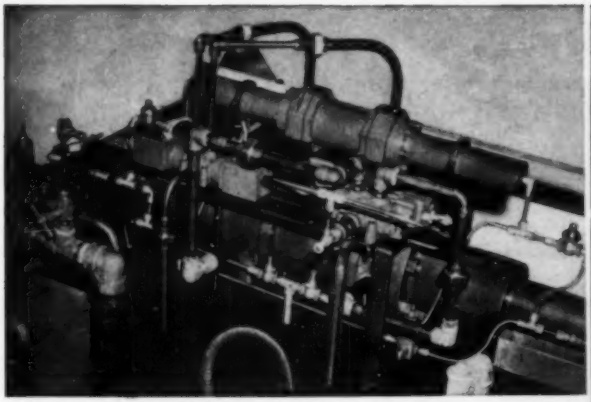
(*Continued from page 44*)

Frothingham, John L., *Pittsburgh, Pa.*
Gross, William F., *San Diego, Calif.*
Maki, Teuvo R., *Houghton, Mich.*
Procopi, John, *Phila., Pa.*
Stanford, George W., *New York, N. Y.*

APPLICANTS FOR JUNIOR MEMBERSHIP

Albright, Melvin A., *Ft. Bragg, N. C.*
Anderson, James Ellis, Jr., *Binghamton, N. Y.*
Arnold, Richard A., *Columbus, Ohio*
Auro, Michael A., *Danville, Pa.*
Bach, W. E., *Cincinnati, Ohio*
Beattie, Robert D., *Arlington, Mass.*
Belz, Lawrence H., *Havertown, Pa.*
Boehm, Elmer L., *Cincinnati, Ohio*
Bolduc, Oliver J., *Chicago, Ill.*
Bourgeois, H. S., Jr., *Houston, Tex.*
Bournia, Anthony, *Richland, Wash.*
Breen, William C., *Houston, Tex.*
Bucklin, R. W., *Houston, Tex.*
Chapman, Kenneth G., *Brooklyn, N. Y.*
Colton, John White, *New York, N. Y.*
Corkill, Donald, *Borger, Tex.*
Daly, Richard J., *St. Louis, Mo.*
Davenport, Gordon E., *Texas City, Tex.*
Detamore, Loren A., *Jamaica, N. Y.*
Dewa, Alexander J., *Detroit, Mich.*
Eatman, Phelan W., *Houston, Tex.*
Engelhorn, Curt G., *New Brunswick, N. J.*
Fesen, Robert F., *Bronx, N. Y.*
Fleetwood, Wade, Jr., *Dunbar, W. Va.*
Garcia, Carlos Torres, *Coimbra, Portugal*
Garst, Joseph H., *Kansas City, Mo.*
Gibbs, George B., *Houston, Tex.*
Gilchrist, M. Clare, *Waynesboro, Va.*
Goris, David Lee, *So. Charleston, W. Va.*
Graeber, C. R., Jr., *Charleston, W. Va.*
Gregory, Vinton E. H., *Agawam, Mass.*
Hainbach, James J., *Tulsa, Okla.*
Hatch, Dwight E., *Oak Ridge, Tenn.*
Heitzman, Dick, *Scotia, N. Y.*
Heyson, George H., *Charleston, W. Va.*
Hickerson, Robert C., *Chattanooga, Tenn.*
Hoerner, George M., Jr., *Parlin, N. J.*
Homan, Charles J., *Evanston, Ill.*
Honnold, James L., *Phila., Pa.*
Katz, Bruno, *New York, N. Y.*
Klohr, James W., *Whittier, Calif.*
Knabel, Arthur J., *Charleston, W. Va.*
Koubek, Francis J., *Baltimore, Md.*
Kromen, George, *St. Louis, Mo.*
Lamoree, D. J., *Hazel Crest, Ill.*
Leonard, Silvester C., *Lawrence, Kan.*
Lombard, Charles R., Jr., *Fredericksburg, Va.*
Lunn, Richard Harry, *Pittsburgh, Pa.*
Lux, M. P., *Monsanto, Ill.*
Lyon, Ward L., *Richland, Wash.*
Manchester, Andrew H., *Wilmington, Del.*
Manogue, William H., *Baltimore, Md.*
Marti, George, Jr., *Baton Rouge, La.*

(*Continued on page 50*)



NICKEL ALLOYED STEELS, heat treated to high strength values, provide parts of extreme toughness and reliability for Harwood intensifiers, such as this typical installation in a glass company's plant.

TYPE 316 STAINLESS IS UTILIZED in Foxboro indicators and recorders such as these shown in use with a Harwood intensifier.

NICKEL ALLOYS HELP MAKE

PRESSURES UP TO 2000 ATMOSPHERES

COMMERCIALLY PRACTICAL

New equipment and processes now being used to explore pressures up to 10,000 ATMOSPHERES

Heretofore, the highest pressure commonly used industrially has been for ammonia synthesis at 1000 atmospheres...

Now, however, pressures of at least 2000 atmospheres (30,000 p.s.i.) already serve production processes, and apparatus capable of delivering pressures up to 200,000 p.s.i. has been designed by the Harwood Engineering Company of Walpole, Mass.

To secure essential stamina in high pressure heads of intensifiers, as well as in reactor vessels, valves and fittings, Harwood engineers fabricate these parts from nickel alloyed steels. The types used, include S.A.E. 4340 (nickel-chromium-molybdenum), S.A.E. 3250 (1.75% nickel-chromium) and S.A.E. 3450 (2% nickel-chromium). They are heat treated to very high strength, with a double tempering treatment after liquid-quenching.

Developed for use in conjunction with these new high pressure units are instruments for measurement and control... produced by The Foxboro Company of Foxboro, Mass.

Foxboro utilizes a nickel-alloyed stainless steel, Type 316, containing 17% chromium, 12% nickel and 3% molybdenum, for heavy duty helical elements that determine pressures up to 80,000 p.s.i. Results in service prove the correctness of choosing Type 316, since it resists corrosion from a wide variety of chemicals, and combines good spring qualities with high yield point after suitable cold working.

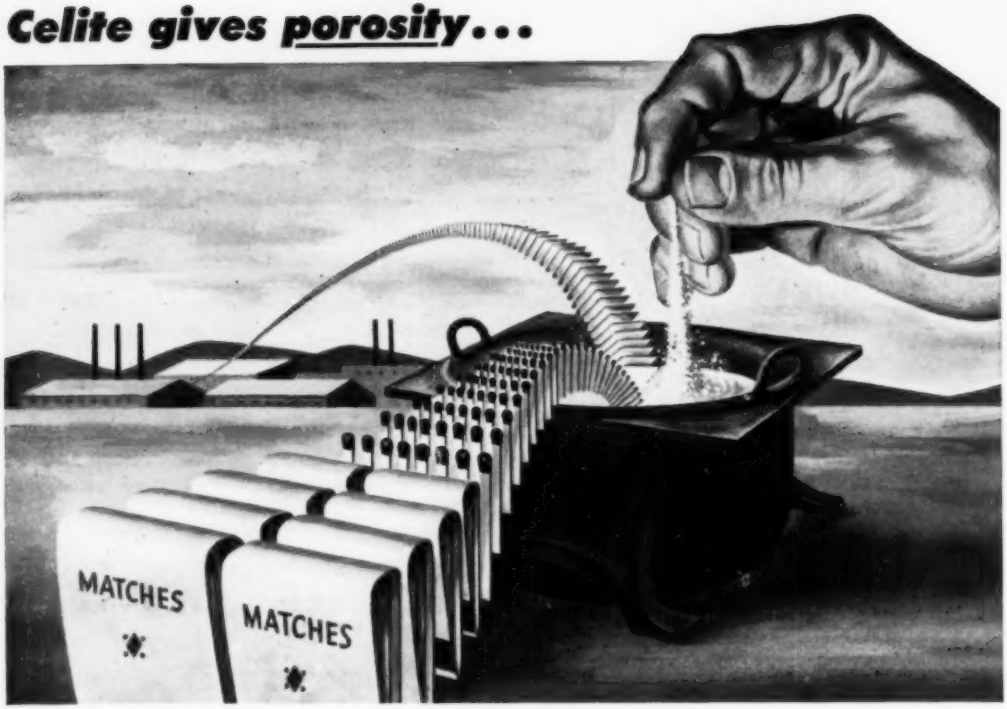
Harwood, also, uses Type 316... sometimes to line composite tubes, and sometimes as solid tubing to handle pressures up to 200,000 p.s.i.

Thus, nickel-containing alloys play an important role in developments which may open new industrial frontiers.

At present, the bulk of nickel produced is being diverted to defense. Through application to appropriate authorities, nickel is obtainable for the production of engineering alloy steels for many end uses in defense and defense supporting industries. Counsel and data on alloys containing nickel, for your present or future projects, may be had for the asking. We invite your inquiries.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

Celite gives porosity...



Adding "Safety Valves" to match heads

Incorporated in match heads, Celite Mineral Fillers act as "safety valves" to prevent flare-up and kill afterglow.

The explanation: *Celite's porous, thin-walled, cellular structure gives the match heads greater porosity so that gas can escape quickly.*

Celite's abrasive quality also makes matches easier to strike. And from a production line standpoint, the high absorptive capacity of this mineral filler speeds drying of the match heads . . . while its light weight and great bulk improve dispersion of the active chemicals in the match head mix.

These and other unusual physical characteristics adapt Celite Mineral Fillers to numerous industrial uses.

THESE CELITE PROPERTIES BENEFIT MANY TYPES OF PRODUCTS

Celite's minute, chemically inert particles have an irregular, spiny structure—which accounts for their efficiency as a delicate abrasive in polishes, as a flatting agent in paints, varnishes and lacquers, and as a reinforcing agent for paint films and rubber products.

Celite powders can absorb up to three times their own weight of liquid—making them particularly useful in preventing ammonium nitrate crystals from caking, in absorbing liquid insecticide poisons, and in controlling pitch trouble at paper mills. And because the loose weight of Celite averages only 10 pounds per cubic foot—these mineral fillers are employed to fluff-up insecticide dusts and household cleansers, as well as to extend white pigments in paper manufacture.

If you are looking for the "extra something" to lift your product above competition—at no extra cost—why not discuss your problem with a Johns-Manville Celite Engineer? For further information and samples, write Johns-Manville, Box 60, New York 16, N. Y. In Canada: 199 Bay Street, Toronto 1, Ontario.

CHECK LIST OF PRODUCT BENEFITS OBTAINABLE AT LITTLE COST WITH CELITE MINERAL FILLERS

- Added Bulk
- Better Suspension
- Faster Cleaning Action
- Greater Absorption
- Improved Color
- Better Dielectric Properties
- More Durable Finish
- Increased Viscosity
- Elimination of Caking
- Higher Melting Point
- Better Dry Mixing
- Improved Dispersion
- Greater Porosity

JOHNS-MANVILLE JM PRODUCTS

Johns-Manville CELITE®

MINERAL FILLERS

TREASURER'S REPORT

The accompanying balance sheet and statement of income and surplus have been examined by F. W. Lafrentz & Co., certified public accountants of 100 Broadway, New York, N. Y., and in their opinion present fairly the financial position of the American Institute of Chemical Engineers at December 31, 1951, and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

C. R. DeLONG, *Treasurer.*

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
COMPARATIVE BALANCE SHEET
DECEMBER 31, 1951 and 1950

Assets

	1951		1950	
Current Assets:				
Cash on hand and demand deposits		$110,110.83		$115,214.70
U. S. Government and other securities, at cost including accrued interest and dividend (Total market value and redemption value 1951, $95,757.00; 1950, $74,450.50)		96,480.55		74,427.36
Accounts Receivable:				
Membership dues and entrance fees, less reserve for doubtful accounts	$ 1,478.50		$ 1,206.10	
Advertising, Subscriptions, etc.	12,115.64		3,360.76	
Meetings advances	2,300.00	15,894.14	800.00	5,366.86
Inventory, at cost:				
Paper stock	$ 10,390.10		$ 5,000.46	
Postage stamps	463.85	10,853.95	538.13	5,538.59
Total Current Assets		$233,339.47		$200,547.51
Deposits at U. S. Post Office and United Air Lines, Inc.		1,040.31		781.36
Furniture and fixtures, at cost less depreciation		10,878.14		9,036.85
Deferred charges		176.05		1,792.48
Total		$245,433.97		$212,158.20

Liabilities

Current Liabilities:				
Accounts payable, printing and other expenses		$ 11,431.24		$ 7,074.26
Total Current Liabilities		$ 11,431.24		$ 7,074.26
Deferred Income:				
Dues paid in advance	$ 54,023.65		$ 62,667.26	
Subscriptions	10,337.69		12,584.76	
Other payments received in advance	1,887.22	66,248.56	2,041.40	77,293.42
Reserves:				
Chemical Engineering Education Projects Fund	$ 2,394.44		1,912.21	
Student Meetings Fund	41.26		41.26	
Magazine Publication Program	26,614.90	29,050.60	17,873.91	19,827.38
Surplus		138,703.57		107,963.14
Total		$245,433.97		$212,158.20

COMPARATIVE STATEMENT OF INCOME AND SURPLUS
FOR THE YEARS ENDED DECEMBER 31, 1951 and 1950

	1951		1950	
INCOME:				
Membership dues	$166,452.47		$146,712.31	
Less allocation to subscriptions @ $4.50 per member	53,724.54	$112,727.93	44,924.18	$101,788.13
Membership entrance fees		14,030.00		11,485.00
Magazine income		206,388.18		158,173.78
Emblems, binders and preprints, net sales		1,748.00		1,347.12
Surplus from Meetings		3,270.96		3,219.00
Interest on investments		1,500.65		1,765.50
Total Income		$338,665.72		$277,778.53

	1951		1950	
EXPENSES:				
General Operations:				
Magazine expenses	$109,064.07		$ 85,698.47	
Salaries and commissions	121,784.65		97,030.58	
Employees Retirement Plan	4,898.32		5,939.33	
Federal Insurance Contributions	1,197.08		.....	
Rent and electricity	12,801.00		12,552.59	
Printed material, stationery, postage, telephone and telegraph	18,540.07		22,641.90	
Meetings expenses, travel, etc.	11,110.03		9,772.95	
Auditing	1,085.20		1,075.91	
Provision for depreciation—Furniture and fixtures	1,994.99		1,621.15	
Provision for doubtful accounts—Dues	3,021.60		3,045.27	
Awards	1,806.59		.....	
Miscellaneous	3,990.81	$291,294.39	3,169.19	$242,547.44
Other Expenses:				
Sundry publications, cost less sales	$ 2,636.32		$.....	
Participation and contributions to professional groups	3,464.40		1,947.90	
Committee expenses	1,787.19	7,889.91	3,632.51	5,580.41
Total Expenses		$299,184.30		$248,127.85
Net Income for year		$ 39,481.42		$ 29,650.68
Surplus at beginning of year		125,837.05		96,186.37
		$165,318.47		$125,837.05
Deduct:				
Reserve for Magazine Publication program		$ 55,000.00		$ 55,000.00
Less net expenditures to end of year		28,385.10		37,126.09
Magazine Publication program		$ 26,614.90		$ 17,873.91
Surplus at end of year		$138,703.57		$107,963.14

Secretary's Report

S. L. TYLER

THE June Meeting of the Executive Committee contained several important matters but, because these have been discussed quite thoroughly by mail and in person, it was not necessary to have a formal meeting of the Committee and therefore the actions reported were taken as a mail ballot. The Minutes of the Executive Committee meeting of May 11, 1952, were received and approved and also the Treasurer's report and bills for the month of May were approved for payment.

The candidates for membership whose names appeared in the May issue of "C.E.P." were elected to membership in the grades indicated. Forty-eight Student members were also elected. The following Membership Committee appointments were made: Sven England, representing the Ohio Valley Section, J. R. Nelson, representing the Louisville Section and W. R. O'Keefe, Jr., representing the Eastern Connecticut Engineers Club. William Licht, Jr., was appointed counselor of the student chapter at the University of Cincinnati to succeed R. S. Tour, and J. A. Gerster was appointed counselor of the student chapter at the University of Delaware to succeed L. W. Gleekman. O. T. Zimmerman was appointed counselor for the recently approved student chapter at the University of New Hampshire. W. C. Brock, R. Anderson Dye and W. H. Fulford were placed on the Suspense List because of entry into the Armed Forces. We are pleased to report that H. A. Golle and P. W. Riegelhaupt have been removed from the Suspense List because of their return to civilian status. Thirteen resignations from membership were accepted.

W. L. McCabe was appointed representative of the Institute at the annual meeting of the International Organization for Standardization held in New York City in June.

The following Resolution was approved and was sent to the family of the late Dr. Albert B. Newman:

Albert B. Newman

WHEREAS, the passing of Albert B. Newman in New York City, on May 9, 1952, removed from the membership of the American Institute of Chemical Engineers a valued and respected member; and

WHEREAS, throughout the entire thirty-seven years of his membership he gave freely of his time in furthering the aims and objectives of the Institute; and

WHEREAS, he had served the Institute as a director for the period 1936, 1937 and 1938; and again in 1940, 1941 and 1942; and as vice-president in 1947; and as president in 1948; and

WHEREAS, he served on many of the important committees of the Institute, particularly as a member and later as chairman of the Chemical Engineering Education and Accrediting Committee; all of which service was of extreme value to the Institute and greatly appreciated; and

WHEREAS, in his activity as educator in the field of chemical engineering he has contributed greatly to the advancement of the profession;

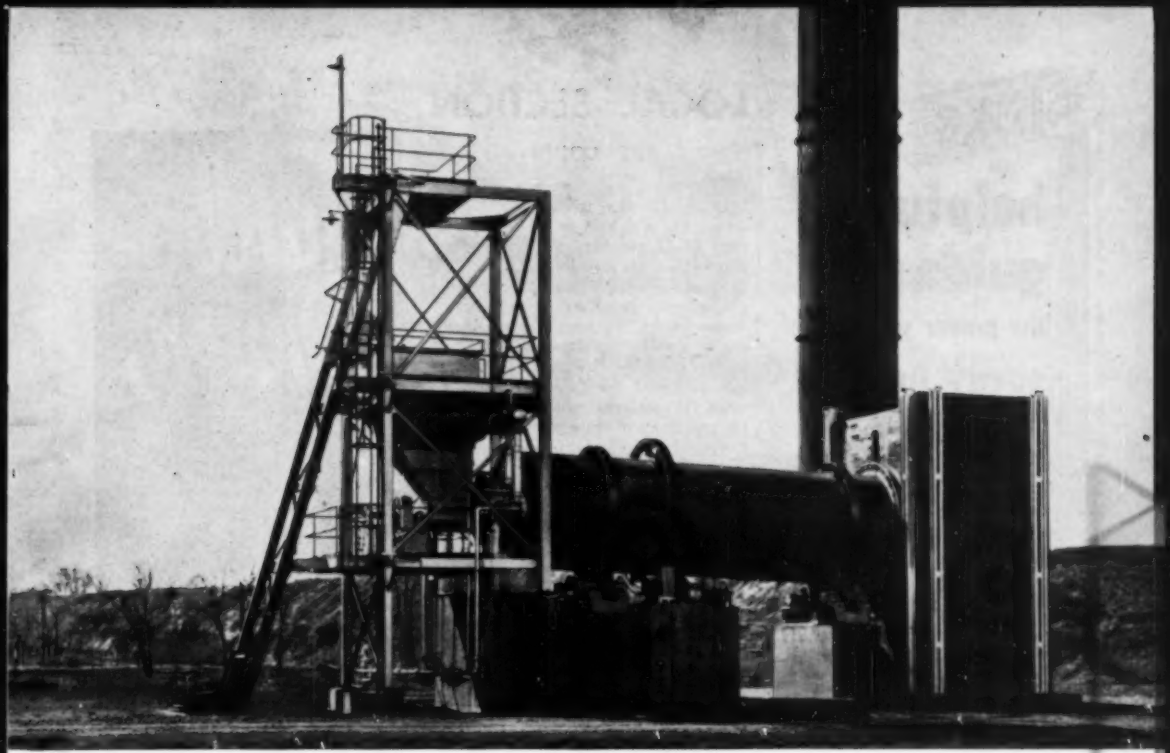
THEREFORE BE IT RESOLVED, that the Council of the American Institute of Chemical Engineers records with a great sense of loss and sorrow his passing; and

BE IT FURTHER RESOLVED, that this Resolution be made a part of the Minutes of the meeting and a copy sent to the family of the late Albert B. Newman.

CANDIDATES

(*Continued from page 46*)

Mattern, Robert V., *Houston, Tex.*
Millen, I. William, *Mattapan, Mass.*
Miller, Robert H., *Niagara Falls, N. Y.*
Monroe, Ross R., *So. Charleston, W. V.*
Newman, Blaine F., *Chicago, Ill.*
Null, Harold R., *Knoxville, Tenn.*
O'Connor, Eugene H., *Army Chemical Center, Md.*
O'Donnell, Neil B., *Melrose, Mass.*
Oldenburg, John R., *Edgewood, Md.*
Oliver, Earl D., *Madison, Wis.*
Pearsall, John F., *Houston, Tex.*
Phillips, Robert C., *Cleveland, Ohio*
Potochnik, Frank S., *Pittsfield, Mass.*
Price, Billy Glenn, *Corpus Christi, Tex.*
Redington, John M., *So. Charleston, W. Va.*
Remy, Edwin D., *Baton Rouge, La.*
Richardson, Kenneth W., *Jr., Akron, Ohio*
Rodrigues, James L., *Springfield, Mass.*
Roe, George R., *Amherst, Va.*
Ruoff, James S., *Army Chemical Center, Md.*
Ryrholm, Robert W., *New York, N. Y.*
Samples, John R., *So. Charleston, W. Va.*
Sayles, Donald A., *Buffalo, N. Y.*
Schrodt, Paul R., *Louisville, Ky.*
Siegel, Henry I., *Brooklyn, N. Y.*
Smith, Charles W., *Bainbridge, N. Y.*
Smith, John E., *Webster Groves, Mo.*
Speed, David B., *Chicago, Ill.*
Springmuhl, Carlos E., *Gautemala City, Guatemala, C. A.*
Stelzer, Glenn I., *Elsmere, Del.*
Stonger, Donald L., *Independence, Mo.*
Sturzenegger, Aug., *Clifton, N. J.*
Styslinger, James R., *New York, N. Y.*
Svoboda, Elvin V., *Waco, Tex.*
Vincent, Philip Seymour, *Cleveland, Ohio*
Voelker, Clarence E., *So. Charleston, W. Va.*
Waina, R. I., *Cleveland, Ohio*
Witter, William T., *St. Louis, Mo.*
Work, Richard D., *Berkeley, Calif.*
Wright, J. O. B., *Chattanooga, Tenn.*
Zahl, Philip M., *Midland, Mich.*



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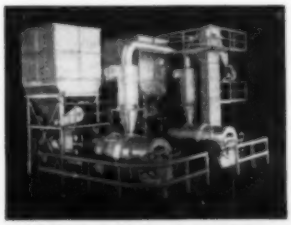

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BULLETIN 14 Nozzles for metal cleaning operations.

BULLETIN 16 Pneumatic Atomizing Nozzles for humidifying and spraying water, chemical solutions, oil, etc., in a completely atomized form.

BULLETIN 19 Spra-Rite Nozzles, vane-type, producing uniform, full-cone spray for industrial processes such as air and gas washing.

BULLETIN 20 Atomizing Nozzles for maximum fluid breakup in applications requiring diffusion of liquids.

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LOCAL SECTION

ST. LOUIS

The annual inspection trip was made May 24. The Owens-Illinois Glass Co., Alton, Ill., was host to the Section. A total of 71 members and guests took part in the trip, including 24 ladies.

A plant inspection was preceded by a 25-min. color-sound film, a composite of scenes from various Owens-Illinois plants, showing the manufacture of glass bottles, closures, and cartons. The film also explained the careful testing and control procedures which characterize the operations of these plants, as well as the research being done to improve and develop products. The plant trip lasted about one and one-half hours, during which time the group saw the glass furnaces and several types of bottle-making machines.

Reported by D. S. Weddell

NORTHERN CALIFORNIA

Approximately eighty-two members and guests, present at the May 19 meeting at the Engineers' Club in San Francisco, heard George S. Smith, of the U. S. Western Regional Research Laboratory, discuss "Application of Steam Injection in Heating and Concentration Processes." Mr. Smith described the results of research on the problem of heating materials at high temperatures for short periods of time followed by rapid cooling. This operation is of great importance in the food processing industry.

Reported by D. F. Rynning

SOUTHERN CALIFORNIA

Eighty-six members and guests attended this section's monthly dinner meeting held at Old Dixie Barbecue, in Los Angeles, June 17. The guest speaker was W. Sandham, automotive engineer for the General Petroleum Corp., who discussed "The 1952 Mobilgas Economy Run and Driving Techniques to Improve Gasoline Mileage." He explained what an enormous undertaking the Mobilgas Economy Run represents.

Portable gas stations, flagmen, telephone men, refueling crews, checkers, timers, car patrols, equipment mover, and weather experts were a part of the more than 800 people who had to be transported, housed and boarded at various locations along the 1415 mile three-day run.

The purpose of the annual contest is to provide an impartial, practical test of new model automobiles under exactly the same conditions the average motorist experiences.

Reported by Gale S. Peterson

(*More Local Section on page 54*)

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Turbo-Dryer®

...gentle handling in drying — through repeated piling and spreading.

...repeat orders from nationally known concerns testify to its merits.

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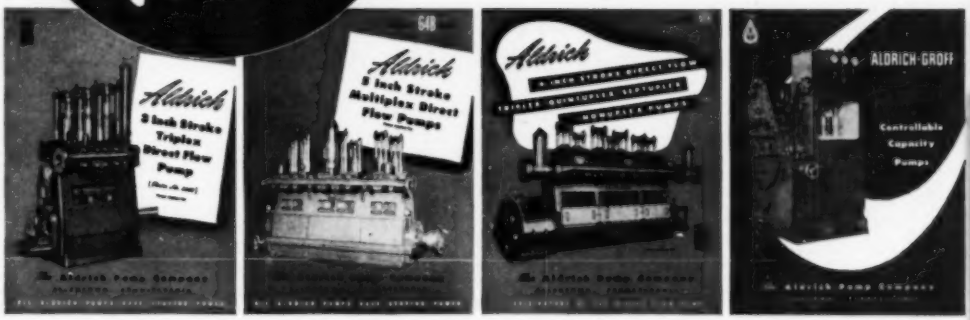
For Men Who Specify, Buy or Use Reciprocating Pumps



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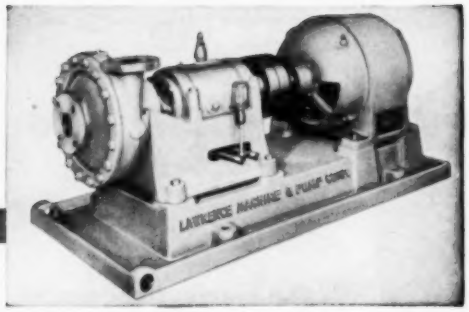

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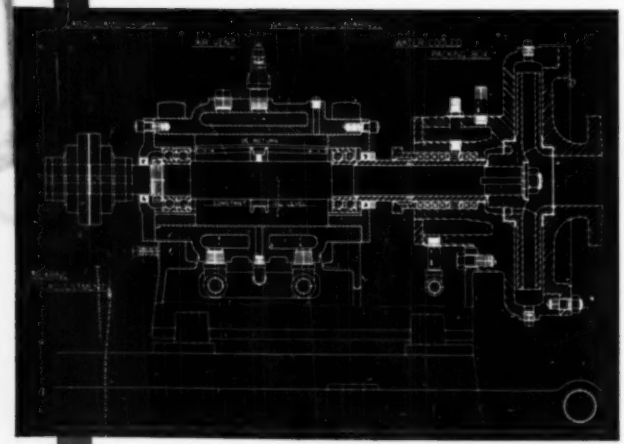

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375 MARKET STREET, LAWRENCE, MASS.

LOCAL SECTION NEWS

(*Continued from page 52*)

NEW ORLEANS

The 1952 "Year Book of Registered Professional Engineers and Land Surveyors" of the Louisiana Board lists those registrants who were licensed to practice as of Feb. 1, 1952. In the three general classifications the totals are:

a. Professional Engineers	2657
b. Land Surveyors	129
c. Civil Engineers as Public Employees *	358
Total	3144

* Civil engineers fully registered in that branch are included in (a) whereas classification (c) covers public employees who were allowed to register in that category only during the first year of operation of Act 73 of 1950; they do not have the full qualifications for registration normally required for registration as civil engineers.

Of the 2657 licensed in the various branches of professional engineering, 238 or 9.0% are licensed to practice in chemical engineering. Of these 238, the majority are registered in chemical engineering alone but several are registered in other branches also. The breakdown of the 238 licensed chemical engineers in this respect is as follows:

In Chemical Engineering (alone)	209
In Chemical and Mechanical	20
In Chemical and Petroleum	7
In Chemical and Civil	1
In Chemical, Mechanical and Electrical	1
Total	238

Of sixty-seven members of the New Orleans Section, thirty-one or 46.3% are registered in Louisiana. Of the fifty-one members working or living in the City of New Orleans twenty-eight or 54.9% are licensed.

In the engineering branches the licensed members of the New Orleans Section number as follows:

In Chemical (alone)	26
In Mechanical (alone)	1
In Chemical and Mechanical	3
In Chemical, Mechanical and Electrical	1
Total	31

There are other A.I.Ch.E. members in Louisiana who are in other sections and many who do not belong to any section.

Statistics Prepared and Reported by
Henri J. Molaison

DETROIT

Effective July 1, officers are:

Chairman.....L. R. Chrzan
Vice-Chairman.....J. W. Shier
Secretary.....T. J. Carron
Treasurer.....R. C. Rogge
Members-at-Large, Board of Directors
D. L. Miller, R. E. Cavanaugh

Reported by T. J. Carron

ROCHESTER

The final meeting of the 1951-1952 season was the annual banquet held May 4, 1952, at Lorenzo Restaurant, with approximately 125 people attending.

The year's activities were reviewed by Irving Siller, secretary.

Officers for the 1952-1953 season were elected as follows:

Chairman—R. R. Ross, Eastman Kodak Co.
Vice-Chairman—I. Siller. The Pfaudler Co.
Secretary—W. F. Kaiser, Eastman Kodak Co.
Treasurer—J. M. Lindsley, Eastman Kodak Co.
Directors—F. W. Kunkel, Eastman Kodak Co.; E. K. McLean, Distillation Products Industries

A. P. Colburn, of the University of Delaware, speaker of the evening, talked on "The Expanded Roll of the Engineer Today." Dr. Colburn discussed the manner in which engineers and businessmen could contribute to the cause of world cooperation and world peace.

Reported by Irving Siller

CHARLESTON

The last meeting of the year 1951-1952 was held May 23 at the Kanawha Country Club.

Dinner was served to the 150 members present and their guests. After the dinner Chairman Porter summarized the activities of the past year in a report to the members and announced that the winning candidates of the recently conducted election by mail are:

Chairman.....Roland Voorhees
Vice-Chairman.....H. F. Lewis
Secretary.....A. G. Draegar
Treasurer.....E. H. Ten Eyck, Jr.
Member-at-Large of Executive Committee.D. B. Benedict

Guests of the Section at the dinner were W. H. Jaquith and Leroy S. Clark of the Marine Midland Trust Co., New York. Mr. Clark gave a talk, liberally interspersed with amusing anecdotes, on "A Banker Looks at Engineering," in which he pointed out some ways in which banking and engineering are related, and reviewed the general philosophy of both fields of endeavor.

Reported by G. K. S. Connolly

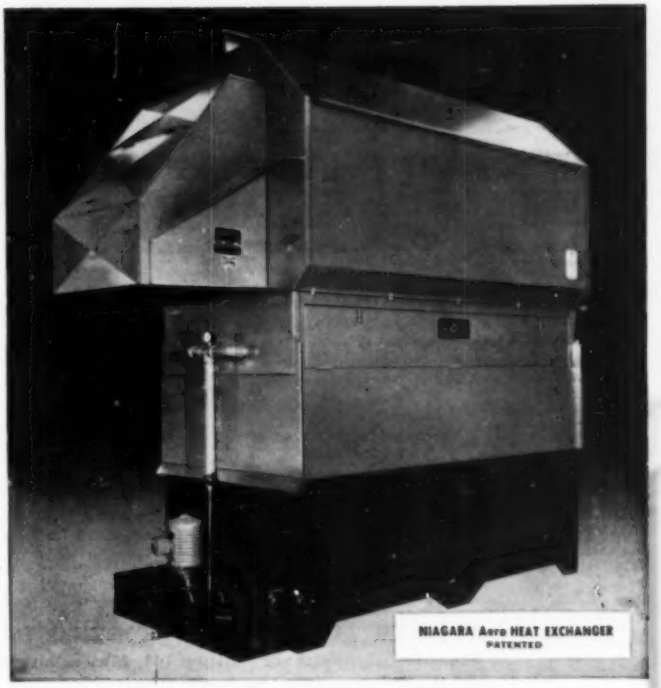
TWIN CITY

At our final spring meeting, May 21, at Rene's Restaurant in St. Paul, forty-two members were present for the dinner and program.

Jose B. Calva of the J. B. Calva Co. gave an informal talk titled "Economic Status of the Chemical Engineer."

Dr. Calva urged greater participation by chemical engineers in civic affairs.

(*Continued on page* 56)



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LOCAL SECTION NEWS

(*Continued from page 55*)

The evening was closed on an outdoor note with two movies, "Duck Hunters' Dilemma" and "Water Fowls in Minnesota."

Reported by R. H. Fredrickson

NEW JERSEY

For the 1952-53 season, the following officers were elected:

Chairman.....T. H. Kelly
Chairman-Elect.....E. F. Jennings
Secretary.....O. C. Karkalits
Treasurer.....Ralph Cohen
Exec. Comm: G. C. Keeffe, T. S. Leary, D. D. MacLaren, N. Morash

This Section concluded its third year of operation with an all-day meeting on May 6 at the Hotel Essex House in Newark. The morning program consisted of two symposia: Crushing & Grinding, featuring E. L. Piret of the University of Minnesota, H. W. Erickson of Allis-Chalmers, and J. H. Foote of Pulverizing Machinery Co.; Instrumentation for Process Control, featuring M. D. Shriver of Panellit, E. T. Davis of Leeds & Northrup, and Clarridge and Berk of Taylor Instrument Cos.

The afternoon meeting was on the status of the chemical engineer. T. A. Marshall, Jr., of the Engineering Manpower Commission, spoke on the engineer and national security. F. J. Van Antwerpen, editor of "C.E.P.", painted the salary picture; and G. P. Whitcomb of American Cyanamid discussed employment opportunities. H. B. H. Cooper of Colgate moderated the panel discussion which followed.

Reported by D. A. Levenson

COLUMBIA VALLEY

At the annual meeting held in May, the following officers were elected for the year 1952-53:

Chairman.....W. M. Harty
Vice-Chairman.....H. E. Hanthorn
Sec.-Treas......E. R. Irish
Members. Exec. Comm.: J. Emmett Maider, Jr., C. F. Falk, V. R. Cooper
Ex officio-Past Chairman...C. E. Kent

Reported by H. E. Hanthorn

SOUTH TEXAS

This Section had a field trip through the Cameron Iron Works, Houston, Tex., June 20. The social hour, dinner, and meeting were held at the Old Hitchin' Rack at Addicks, Tex. The speaker of the evening was Parker Frisselle, manager, of market research, Dow Chemical Co., Midland, Mich. He talked on "The Functions of Chemical Market Research."

Reported by J. B. Platz

CHICAGO

The annual meeting was held May 21 in the Western Society of Engineer's Suite with more than 80 present for dinner. Election of officers resulted in the following:

Chairman.....E. N. Mortenson
Vice-Chairman.....J. R. Blizzard
Secretary.....K. W. MacFie
Treasurer.....T. H. Matthews, II

The evening's speaker was Dr. A. W. Davison, director of research, Owens-Corning Fiberglas Corp., who talked on "Recent Developments in the Glass Fiber Industry." He explained the great increase in the strength and flexibility of glass resulting from fiberizing and how this is utilized structurally.

This was the final meeting of the season, and next fall the first regular meeting will be held at new quarters in the Builders' Club.

Approximately 130 members and guests met on the occasion of the Section's Annual Student Meeting, when members of A.I.Ch.E. chapters at Northwestern University and Illinois Institute of Technology were guests.

William I. Burt, President, A.I.Ch.E., discussed briefly the national organization and activities.

Another speaker was M. E. Barnes, of Armour & Company, who spoke on "The Relationship Between Management and Technical Personnel."

Reported by Thorpe Dresser

PITTSBURGH

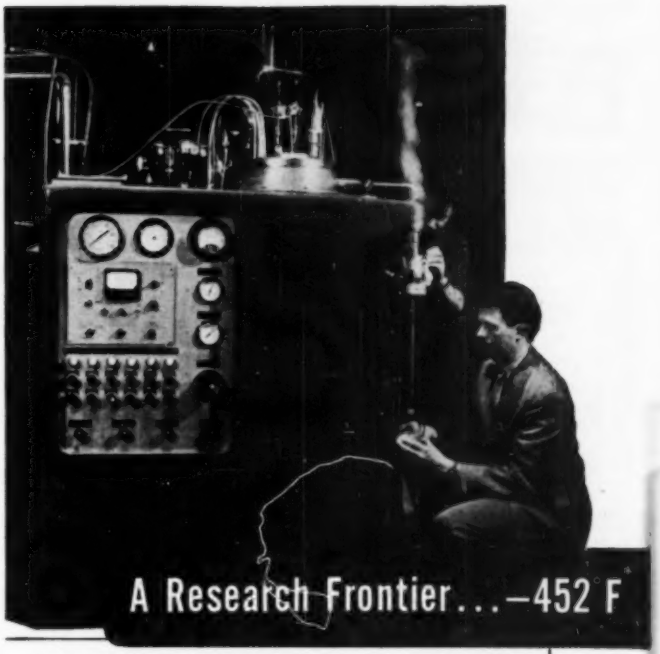
The pipeline transportation of coal was discussed by Howard S. Turner, director of research and development, Pittsburgh Consolidation Coal Co., at the closing dinner meeting of the current season, held May 7 at the College Club.

At the business session, the following were elected officers of the Section for 1952-1953:

Chairman—Eugene Ayres, Gulf Research & Development Co.
Vice-Chairman—W. M. Trigg, Westinghouse Electric Corp.
Secretary—H. L. Kellner, Gulf Research & Development Co.
Treasurer—J. S. Joseph, Koppers Co., Inc.

Dr. Turner underlined the necessity for lessened transportation costs of coal to existing markets, under present competitive conditions. In November, 1950, after experimental and design studies, the Pitt Consol research group decided to construct and operate a full-scale demontration coal pipeline at Georgetown, Ohio; coal-pumping operations began in November, 1951. Such determining factors as attrition, corrosion, flow rates, ΔP (power, pumping requirements), dewatering, and general operability have been investigated and correlated in forecasting the commercial application of the process.

Reported by Hugh L. Kellner



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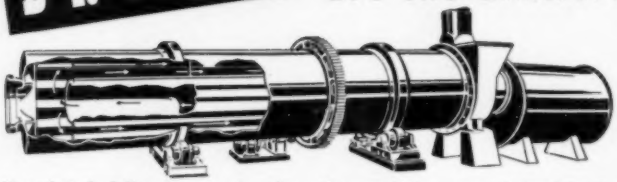

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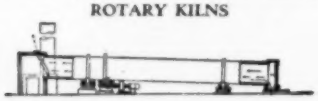

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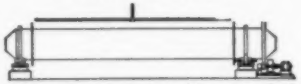

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PEOPLE

Harry B. McClure, vice-president, Carbide & Carbon Chemicals Co., was elected honorary chairman, American Section, Society of Chemical Industry, for the year 1952-53.

Other officers elected were: honorary vice-chairman, Lauren B. Hitchcock, president, National Dairies Research Corp., Oakdale (L. I.) N. Y.; honorary treasurer, Cecil L. Brown, assistant director of research, Standard Oil Development Co., New York, and honorary secretary, Frederick W. Adams, director of research, Spool Cotton Co., New York. Included among members of the Executive Committee for three years are Emil Ott, Hercules Powder Co., Wilmington, Del., and Raymond Stevens, Arthur D. Little, Inc., Cambridge, Mass.

Mr. McClure joined Carbide & Carbon Chemicals in 1928 and in 1944 was advanced to the vice-presidency of his company, which is a division of Union Carbide & Carbon Corp. During World War II, he was consultant to the N.D.R.C. and was associated also with the War Production Board.

Max Neuhaus has recently been elected vice-president of Jefferson Chemical Co., Inc., New York. Since 1948 he has been manager of the technical and research department of the company. Mr. Neuhaus received his B.S. degree from Rice Institute and his Sc.D. from M.I.T.

Elwood I. Clapp, Jr., a graduate of the University of Maine with a B.S. degree, was recently appointed to the market research section, new product development, of American Cyanamid Co., New York. Mr. Clapp was transferred from the chemical engineering division of the company's Stamford (Conn.) research laboratories.

C. E. Bonine, a graduate of Princeton University, has received the appointment as home office sales manager of chemical products sales, Atlantic Refining Co., Philadelphia, Pa. He had been serving as administrative assistant of the section since 1948. Mr. Bonine joined Atlantic in 1941 as a member of the research and development department, where he was stationed until his transfer to chemical products sales.

C. B. CLARK RETIRES

C. B. Clark, director, patent department, American Cyanamid Co.'s Stamford research laboratories since 1932, retired June 30, following twenty-three years of service with the company. Mr. Clark was graduated from St. Lawrence University with a B.S. degree in 1908, and received his M.S. degree in 1911. He was associated with the General Chemical Co. from 1910 to 1929 when he joined the American Cyanamid Co.

Herbert E. Hirschland has received the appointment of director of research with the Metal & Thermit Corp., New York. A graduate of Dartmouth College and of Massachusetts Institute of Technology, Hirschland has been with Metal & Thermit since 1941, when he joined the company's research laboratory staff in Rahway, N. J. In 1946 he left the research field to become a sales engineer in the company's chemical sales division and since 1950 has been assistant sales manager of that division.

Robert J. Phillips has recently received the appointment of operation and maintenance editor with the Gulf Publishing Co., publisher of Petroleum Refiner. Prior to going with Gulf, he had been with Humble Oil & Refining Co., Baytown, Texas, where he was successively junior engineer, assistant engineer, and chemical engineer.

Robert E. Reinker has been named technical adviser to the president of Asahi-Dow Limited, recently formed associate of Dow Chemical International, Limited and the Asahi Chemical Industry Co., Limited, of Japan. Reinker has been superintendent of the Dow Chemical Co.'s saran polymer plant at Midland for the past two years. He has been with Dow since graduating from Case Institute of Technology in 1942, and before entering the saran department was attached to the company's chemical engineering and physical research laboratories.

Frank W. Dittman has joined the Rust Process Design Co., a subsidiary of The Rust Engineering Co., as a process engineer. In his new position Dr. Dittman will handle projects of chemical plant design and construction. He started his career with St. Joseph Lead Co. in research, and after a period of teaching at Cornell University, served as electronics technician with the U. S. Navy taking part in the atom bomb tests at Bikini. On his return he joined the chemical engineering department of Koppers Co. where he specialized in chemical plant design and was in charge of process engineering for the coal-to-oil demonstration plant built for the U. S. Bureau of Mines at Louisiana, Mo.

Charles E. Huckaba, instructor and candidate for a doctor of philosophy degree in chemical engineering at the University of Cincinnati, has been appointed associate professor of chemical engineering at Lamar State College of Technology, Beaumont, Tex. Mr. Huckaba, scheduled to complete requirements for the doctorate in August, will assume his new duties Sept. 1. A 1944 graduate of Vanderbilt University, he took his master's degree from Massachusetts Institute of Technology in 1947.

C. E. Webb was promoted recently from superintendent services at the Sharples Chemicals, Inc., Wyandotte, Mich., plant to assistant vice-president, manufacturing in the Philadelphia executive offices. He has been with Sharples since 1941.

Edward P. Lynch has recently been transferred from the Pittsburgh office of the chemical plants division of Blaw-Knox Co. to the Midwest office located in Chicago. A chemical engineer, he is in the chemical process department.

John E. Swearingen was recently elected a director of Standard Oil Company (Ind.). He joined Standard Oil in 1939 as a chemical engineer in the Whiting (Ind.) research laboratories. In 1947 he was transferred to the manufacturing department of Stanolind Oil & Gas Co., becoming assistant to the vice-president in charge of operations in 1949, and manager of the company's central division a year later. Early in 1951 he was transferred to Stanolind's general office in Tulsa, Okla., becoming a director shortly thereafter. He became general manager of production in Chicago in August, 1951.

C. J. Francisco has been promoted to the newly created post of manager in charge of technical activities for Harvey research center, of Sinclair Research Laboratories, Inc. He joined the organization in 1941. His initial work with the then wartime research center was with the Sinclair development department, pilot plant division. He directed the activities of Sinclair's process design group and subsequently was appointed research director of the cracking division at Sinclair's new Harvey laboratories.

W. R. Riggs has been promoted to the newly created position of manager in charge of general services for the Sinclair Research Laboratories, Inc., at Harvey, Ill., where he has served as general superintendent since 1951.

(More About People on page 60)

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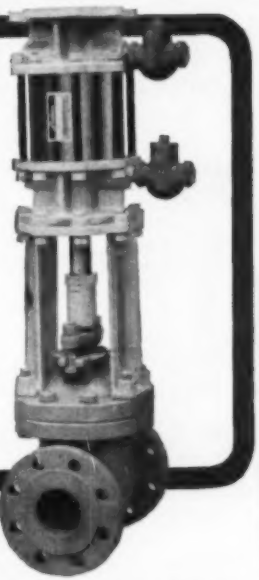
VALVE ACTUATORS



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PEOPLE

(*Continued from page 59*)

E. S. Pettyjohn and **J. D. Parent** have recently been appointed vice-president, and dean, respectively, of the Institute of Gas Technology, Chicago, Ill. The naming of Capt. Pettyjohn, the first in the history of the Institute (whose president is, ex officio, the president of Illinois Institute of Technology) as vice-president, was done in recognition of his contribution, as director, to the Institute's rise in the fields of research and education.

E. S. Pettyjohn

Professor Pettyjohn entered the gas industry in coke-oven operation for Semet-Solvay. Later he became research engineer for the Michigan Gas Association, and subsequently, as associate professor for gas engineering, established the cooperative course in gas engineering at the University of Michigan where he received his B.S.E. and M.S.E. After other assignments, in 1937 he returned to the University of Michigan as associate professor of chemical engineering.

J. D. Parent received his Ph.D. from Ohio State University, served successively on the faculties of Ohio State, Loyola of Chicago, and Kansas State, gaining experience in teaching and research before going to the Institute of Gas Technology in 1943 as supervisor of the chemical engineering section. His first three years at IGT were spent in research and in 1946 he was appointed educational director, which title he held until his recent promotion.

PURDUE ENGAGES WOODS —BENNETT TO FRANCE

The school of chemical and metallurgical engineering at Purdue University, Lafayette, Ind., announces the following addition to its staff, effective Sept. 1, 1952. John M. Woods has been appointed assistant professor of chemical engineering. Mr. Woods took his undergraduate training at the University of Kansas and his graduate work at the Illinois Institute of Technology and the University of Wisconsin. He is now completing requirements for the Ph.D. degree at Wisconsin. He has been assistant professor of chemical engineering at the University of Rhode Island.

Prof. C. O. Bennett, assistant professor of chemical engineering, has received a Fulbright Fellowship and will spend a year teaching chemical engineering at the University of Nancy.

R. H. Boundy, manager of the Dow Chemical Co.'s plastics department since 1945, has been named to head the company's research activities. Dr. Boundy went to Dow as a chemical engineer in 1926 and has been closely associated with many of the company's developments in the fields of hydrocarbons and plastics. He served as assistant director of physical research from 1930 to 1941 when he was appointed assistant to the president. In 1950 Dr. Bundy was elected to the board of directors.

Edgar L. Demarest has recently been appointed West Coast district manager for the Buflovak equipment division of Blaw-Knox Co. He was a sales engineer for the past four years in the New York district sales office. Before joining Buflovak, Mr. Demarest was project engineer with the Heyden Chemical Corp. He is a licensed professional engineer, and a graduate of Cooper Union.

Frank M. Tiller, director of the division of engineering, and professor and head of the department of chemical engineering at Lamar State College of Technology, Beaumont, Tex., will lecture at the National Institute of Oils in Rio de Janeiro, Brazil, this summer at the invitation of the Brazilian government. His lectures will be to graduate students and professors of the Institute on unit operations, distillation, absorption, extraction and filtration. He will visit Brazil under the Exchange Persons Grant conducted by the U. S. State Department. Dr. Tiller will be associated with **B. J. G. Mascarenhas** who was a graduate student under the Lamar Tech professor when he was at Vanderbilt University. Mascarenhas currently is teaching chemical engineering at the Institute.

Norman D. Sixt, technical engineer, has joined the process equipment division of the Rodney Hunt Machine Co., manufacturer of Turba-Film evaporators and Rodney Hunt-Luwa spray dryers. Mr. Sixt was formerly with Susquehanna Chemical and the Barrett division of Allied Chemical and Dye where he specialized in distillation, esterification and evaporation of synthetic organic material.

(More About People on page 63)

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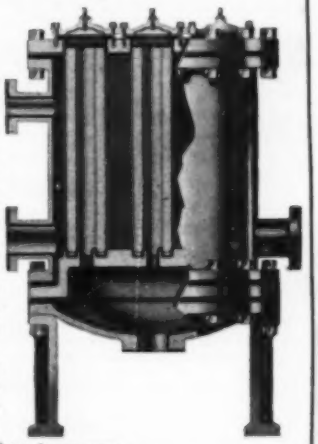

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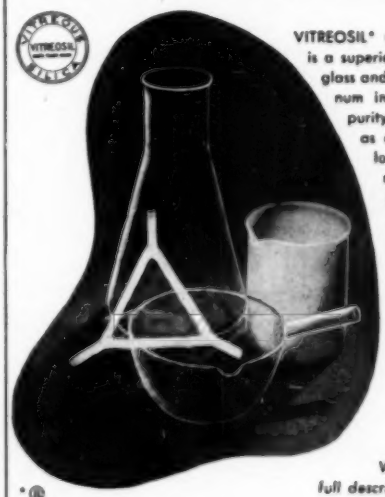

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Technical personnel required for process design and chemical equipment calculations in recently organized organic development department of well established chemical company. Qualifications include knowledge of thermodynamics and fundamentals of unit operations.

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Submit résumé of personal history, education, experience, salary expected. Application confidential.

Director of Development

NITROGEN DIVISION

Allied Chemical & Dye Corporation

ORGANIC DEPARTMENT

HOPEWELL, VIRGINIA

SITUATIONS WANTED

A.I.Ch.E. Members

CHEMICAL PROCESS ENGINEER—B.Ch.E. Age 33. Eleven years' experience in process design and plant development work in petrochemical, butadiene, ammonia, and nitrogenous fertilizer plants where knowledge of distillation, thermodynamics, absorption, heat transfer, etc., were required. Exceptionally well qualified through previous positions for economic evaluation of and development engineering for new projects. Present salary $10,000. Desire engineering position with small or medium-sized organic chemical or petroleum refining operating company. Box 1-7.

CHEMICAL ENGINEER—Ph.D. Twenty years' experience in teaching. At present on leave in industry. Desire change in location. Teaching experience covers every subject. Available in September. Box 10-7.

EXECUTIVE CHEMICAL ENGINEER—B.Ch.E. Licensed, with over twenty years' substantial management experience in production and engineering of caustic/chlorine and organic operations. Seeking connection with broad responsibilities. Box 4-7

PROCESS ENGINEER—D.Ch.E. except for thesis. Ten years research, development, design, pilot plant, production. Thorough knowledge of plastics, polymers, latex, organic chemicals. Permanent, responsible position desired with growing concern in design, production, or research. Box 5-7.

CHEMICAL ENGINEER—M.S. 28. Over four years experience in design, development, technical sales and service in field of petroleum, plastics, chemical equipment. Desire position with broad responsibilities. Own correspondence. Willing to locate. Top ability and initiative. Box 6-7.

CHEMICAL ENGINEER, FOREIGN EMPLOYMENT—B.S., M.S. Three years' diversified experience in design, construction and production. Single, 24, draft-exempt. Seek overseas job, preferably in construction and start-up supervision. Box 7-7.

CHEMICAL ENGINEER—B.S. (1940), Chem.; M.S. (1949) and Ph.D. (1952), Ch.E. 35, married, one child. Eight years' research, development and production experience in alumina, phosphorous, petroleum refining and caustic soda/chlorine. Available July. Box 8-7.

CHEMICAL ENGINEER—D. Eng. (1952). Four years' experience in all phases of chemical process design from pilot plants to production units. Desire position in engineering design and research. Box 9-7.

CHEMICAL ENGINEER

Extensive progressive experience including direction of research and development, plant design and construction, process economics, and waste disposal. Sc.D. in Ch.E. Age 49.
Desire new connection requiring initiative and responsibility on technical or management problems. Would consider a part-time connection on a consulting basis. Box 11-7.

LICENSED CHEMICAL ENGINEER (N. Y.)—33, married, three children. Active member. Thirteen years of accomplishment including supervision of production and process engineering. Submarine officer—World War II. Desire position with greater responsibility in process or project engineering. Box 12-7.

SUPERVISORY CHEMICAL ENGINEER—32, M.S., M.I.T. Licensed P. E. Ten years' varied plant-centered experience from process development and engineering through production supervision. Fields: antibiotics, organics, plastics. Box 13-7.

EXECUTIVE CHEMICAL ENGINEER—Ph.D. 1938. Now completing as director the development of operating plants from process patents. Thorough experience in process engineering design. Specialist in solvent extraction. As head of engineering divisions, handled successfully administration, personnel supervision, technical promotion, cost evaluations and contract negotiations. Available for responsible position with engineering or processing organization. Box 14-7.

CHEMICAL ENGINEER—Registered Professional Engineer. Age 32, married. Seven years' diversified experience in process engineering, pilot plant operation, development and research plus two years' consulting and teaching experience in South America on engineering projects. Will relocate, available immediately. Box 15-7.

Nonmembers

CHEMICAL ENGINEERING EXECUTIVE—Age 38. Registered Ch.E. Experienced in equipment and processes for production of insulating materials, use and handling of resins and asphalt. Excellent years' consulting and teaching experience in South America on engineering projects. Will relocate, available immediately. Box 15-7.

PEOPLE

(*Continued from page 61*)

Joseph W. Lang recently received the appointment of director of research, central research laboratory, General Aniline & Film Corp., New York. Dr. Lang, a graduate of the University of Washington, holds a Ph.D. degree from Columbia University. Prior to going with Aniline, Dr. Lang was with the Du Pont Co. where he had been active in research and chemical engineering work in the organic chemicals department. Until he assumed General Aniline's plant manager post at Rensselaer in July, 1950, he was engaged in both production and process development activities for the company. His headquarters will be at the central research laboratory in Easton, Pa.

W. A. Koehler, professor and head of the department of chemical engineering, West Virginia University, Morgantown, W. Va., became director July 1, 1952 of the Engineering Experiment Station. Dr. Koehler had been serving as acting director. The Engineering Experiment Station is the research agency for the College of Engineering and the School of Mines.

M. F. Ohman and **H. H. Smith** of the Dow Chemical Co. have recently received new appointments as assistant general manager, and production manager of the Western division, respectively. For the past nine years Ohman has been production manager for the Western division. Ohman, associated with Dow since 1930, started as a chemical engineer in the company's Midland (Mich.) headquarters. Later he moved to Long Beach, Calif., where he developed a new process for the reclamation of iodine from oil-well brines for the then Io-Dow Chemical Co., which later joined with Dow's Western division, and in 1941 he moved to Pittsburg as assistant plant superintendent. Smith also began his Dow career in the company's Midland laboratories, and moved to Los Angeles during the war as assistant manager of the government-owned, Dow-operated styrene plant there. He later became manager of the styrene plant, and moved to Pittsburg as assistant production manager of the division.

William H. Schuette is now manager of the newly formed plastics production department of The Dow Chemical Co., Midland, Mich. He had been assistant production manager of polystyrene since 1949. Dr. Schuette began with Dow after receiving his doctor's degree in chemical engineering from Case School of Applied Science in 1941. His research efforts included work with styrene and other hydrocarbons, and in 1943 he became production superintendent for these materials.

DRUMMOND, KATZEN IN VULCAN SHIFT

V. D. Drummond

R. Katzen

V. D. Drummond, at present manager of the engineering division of The Vulcan Copper & Supply Company of Cincinnati, has become manager of the New York office recently opened to represent its engineering, manufacturing and construction divisions. Succeeding Mr. Drummond is Raphael Katzen who will assume the position of manager of the Vulcan engineering division.

Mr. Drummond is a graduate of Oklahoma A & M College and Stevens Institute. Before joining Vulcan he held positions with the American Locomotive Co., Standard Oil Development Co., and Publicker Industries.

Dr. Katzen has been with Vulcan since 1944. Prior to joining Vulcan he was with the Diamond Alkali Co. and the Northwood Chemical Co. He holds degrees from Brooklyn Polytechnic Institute in chemical engineering.

Earl P. Stevenson, president, Arthur D. Little, Inc., Cambridge, Mass., recently received the honorary degree of Doctor of Laws from Wesleyan University, Middletown, Conn., for leadership in industrial research and community endeavors. Mr. Stevenson was educated at Wesleyan University and the Massachusetts Institute of Technology. He joined the staff of Arthur D. Little, Inc., in 1920 and was elected president, in 1935. He is consultant to the Department of Defense and the Chemical Corps.

John F. Conlon, formerly technical director of Acumeter Laboratories, Inc., Newton Lower Falls, Mass., is now associated with the works engineering department of Carbide and Carbon Chemicals Co. at its Texas City (Tex.) plant. During the war Mr. Conlon was engaged in the development of polyethylene resins at the Tonawanda (N.Y.) laboratories of the Linde Air Products Co., and at the Bound Brook (N.J.) plant of Bakelite Corp.

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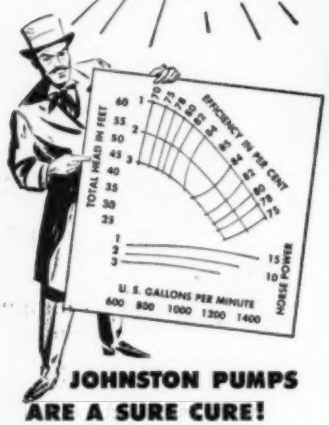
Horsepower Headaches?



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Every Johnston Pump is engineered for the specific duty for which it is intended. Trained hydraulic engineers are available at your nearest Johnston dealer or at the Johnston factory to furnish detailed information, proposals and anything else necessary to cure your particular pumping malady.

The Johnston Wonder Drug

Johnston Turbine Pumps are ideally suited for industrial and municipal applications because of their non-overloading characteristics, simplicity of construction, compactness, ease of installation, elimination of priming, low starting torque, capacity adjustment features and minimum maintenance costs.

Free diagnosis!

No matter what your pumping job, contact your nearby Johnston Dealer or write the factory direct for a free diagnosis of your pumping headaches.

JOHNSTON PUMP COMPANY
3272 EAST FOOTHILL BLVD., PASADENA 8, CALIF.
Headquarters for Vertical Turbine, Mixflow and Propeller Pumps Since 1909

G. E. Seavoy, vice-president of sales, Whiting Corp., Harvey, Ill., has returned from Frankfort, **Germany,** where he attended Achema, the German equivalent of the U. S. chemical exposition. Mr. Seavoy is a graduate chemical engineer, University of Michigan, and for some years was in charge of the Swenson Evaporator Co. division of Whiting Corp., which specializes in the design and manufacture of evaporators, crystallizers, filters and spray dryers.

Richard K. Fliticraft is now assistant research director of Monsanto Chemical Co.'s Merrimac division. In this capacity he is in charge of engineering functions of the research department. Graduated from Rutgers University with a B.S. degree in chemistry in 1942, he joined Monsanto as a control chemist. He has served as group leader in the development department of the company's W. G. Krummrich plant at Monsanto, Ill., as supervisor in the manufacturing department and recently as plant development superintendent. He received his M.S. degree in chemical engineering from Washington University in 1948.

Cary R. Wagner, of General Aniline & Film Corp., New York, was elected chairman of the Executive Committee of the company's board of directors at the June meeting. At the same time, Dr .Wagner resigned his staff post as senior vice-president of General Aniline to enable him to give more time to his chemical consulting practice. In the chemical industry for thirty years, Dr. Wagner became a director of General Aniline in 1947.

John J. McKetta, professor of chemical engineering, University of Texas and chairman of the department from 1949-51, has resigned to become editorial director of Petroleum Refiner, a Gulf Publishing Co. publication. Dr. McKetta received his B.S. degree in chemical engineering at Tri-State College, Angola, Ind., in 1937. After four years in development and production with Wyandotte Chemicals Corp., he was director of chemical development for C. B. Schneible Co. In 1942 he was awarded a teaching fellowship at the University of Michigan, where he took his doctorate in 1946. In addition to his teaching duties at Austin, he has been head of the Texas Petroleum Research Council, a duty he will continue until the expiration of his contract.

Marvin M. Ramer, with Blaw-Knox since August, 1950, has recently been promoted to contract manager at the Southwest division of chemical plants division. In this position he will have charge of all contract preparations and will assist in contract negotiations for the engineering, procurement, and construction activities of chemical plants originating in the Southwest division with headquarters at Tulsa, Okla. Before going to Blaw-Knox he held managerial positions with other chemical companies. Ramer is a graduate of Rensselaer Polytechnic Institute with a degree in chemical engineering.

Edward M. James, assistant to the technical adviser of Lever Brothers Co., Cambridge, Mass., has been elected the forty-third president of the American Oil Chemists Society. He received his B.S. and A.M. degrees from the University of Cincinnati.

Jerome M. Crockin, who has been directing process development activities at Lukenweld, division of Lukens Steel Co., Coatesville, Pa., has been placed in charge of coordinating engineering and manufacturing activities of its cotton seed oil extraction program. A registered professional engineer, Mr. Crockin has had many years' experience in the oil extraction field including development of special oil seed process equipment at Blaw-Knox, as well as process design of synthetic rubber and butadiene plants, recaustization of green liquor in pulp mills, ammonia recovery in nickel ore leaching and other recovery processes. He was educated at Virginia Polytechnic Institute where he received his B.S. and M.S. degrees, and at Massachusetts Institute of Technology. Crockin formerly was an associate professor of chemical engineering at Michigan Mining and Technical College, Houghton, Mich.

Necrology

J. W. WHITNEY

Junior W. Whitney, development chemist, Titanium Pigment Corp., Sayreville, N. J., since 1946, died recently. During World War II, he served as an officer in the U. S. Navy. He received his B.S. in chemistry from Purdue University and his B.S. degree in chemical engineering from Polytechnic Institute of Brooklyn. Mr. Whitney was thirty-two years old.

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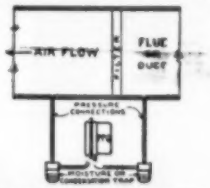
CONTROL—FROM MINUTE CHANGES IN THE RELATIONSHIP OF TWO PRESSURES

MERCOID DIAPHRAGM DIFFERENTIAL PRESSURE CONTROLS OPERATE FROM MINUTE CHANGES (.03"WATER) IN THE DIFFERENCE BETWEEN TWO PRESSURES.

RANGES TO COVER MOST APPLICATIONS (INCHES OF WATER) 6"VAC-TO 6" PRESS., AND 30"VAC. TO 30" PRESS. AVAILABLE FOR VARIOUS CIRCUIT ARRANGEMENTS.

CAN BE FURNISHED IN EXPLOSION PROOF OR WEATHER PROOF CASES.



Illustrated above is a standard application whereby the Type PPQ functions to open (or close) an electrical circuit from a variation in pressure differential due to a clogging filter.

WRITE FOR BULLETIN PPQ

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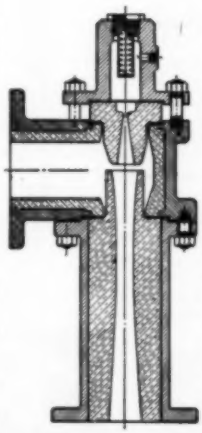

The chemical industries are employing more and more Croll-Reynolds Evactors in vacuum processes where corrosion resistance is a major consideration. These steam jet vacuum units provide pressures ranging from a few inches to a few microns. Croll-Reynolds is a pioneer in the use of new construction materials and our engineers are investigating corrosion problems continually.

Stainless steels, Monel metal, Beryllium copper, Ni-Resist, PMG metal, hard lead, special bronzes, Hastalloy, and Illium are but a few of the special metals which find their way into our equipment. Carbon is used extensively as a lining material, and many plastics including Teflon and synthetic materials are used for making complete Evactors.

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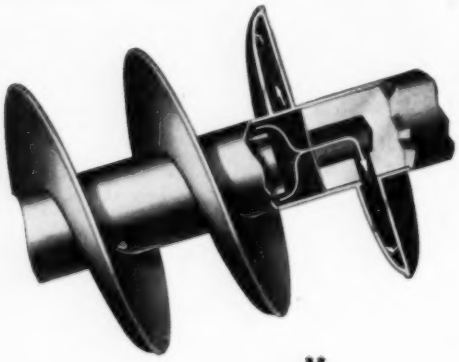
A great new advancement in heat exchangers...



THE holo-flite* PROCESSOR
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A simpler, more compact way to cool slurries, solids or pastes—in continuous flow!

Do you have processes where slurries, solids, pulps or pastes must be cooled or cooked? Do you know you can now handle such processes—*in continuous flow*—in as little as 1/5th the space required by other types of heat exchangers—and with many other important advantages?

The newly-developed HOLO-FLITE Processor is the answer!

what IT IS!

Basically the HOLO-FLITE consists of two or more flights of hollow-bladed screw conveyors. The product to be processed moves in a trough around the conveyor screws. The heat-transfer fluid circulates through the hollow blades and shafts of the conveyor. The product is constantly rotated into, around, under and over the blades and shafts through which the heat-transfer fluid is circulating, assuring quick, uniform heat passage between the two mediums—*as the product is continuously moved along in a bulk-flow without interruptions!*

Get the complete story on HOLO-FLITE *savings and how this new advancement can simplify your processing operations. It is backed by the same organization that pioneered* COTTRELL *Precipitators and* MULTICLONE *Collectors—your assurance of complete dependability.*

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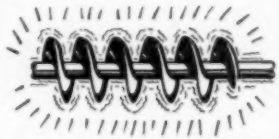
*Reg. T.M.

why IT'S BETTER!

The HOLO-FLITE principle provides many important advantages in modern processing operations...



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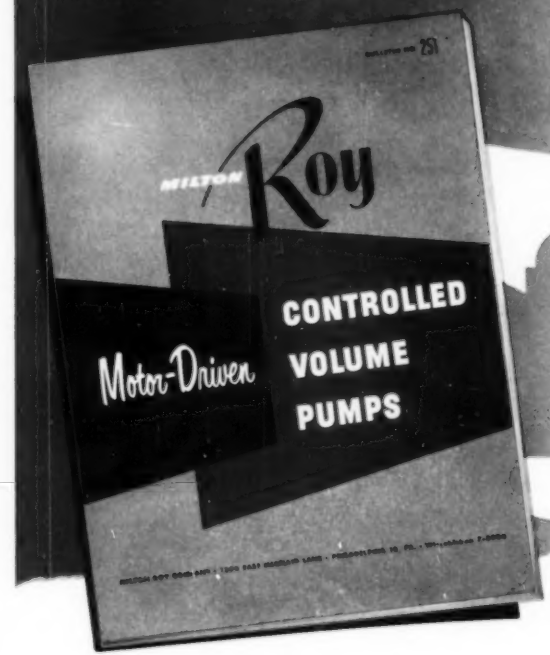

Complete Information In These Pages

What *are* Milton Roy Motor-Driven Controlled Volume Pumps? What materials do they pump? How and where are they used? What different designs and models are available?

The answers to these questions and many more can be found in Bulletin No. 251. This illustrated, 24-page, 2-color bulletin is full of important details. Here is a preview of some of the subjects which are discussed:

- a description of various Milton Roy Motor-Driven Controlled Volume Pumps—the Simplex, Duplex, Constametric, "Titronic," and "miniPump."
- an explanation of the exclusive Milton Roy Liquid End Step-Valve design. This information is useful because it describes the "how" and "why" of this unique non-clogging, self-cleaning liquid end.
- a description of pump capacity regulation by *plunger stroke* adjustment, including screw adjustment, micro adjustment, motorized micro adjustment.
- details on pump capacity regulation by *plunger speed* adjustment, including speedranger adjustment, "Thymotrol" adjustment, Link Belt P.I.V. adjustment.
- data on where Milton Roy Motor-Driven Controlled Volume Pumps can be used.
- capacity-pressure selection tables are included.

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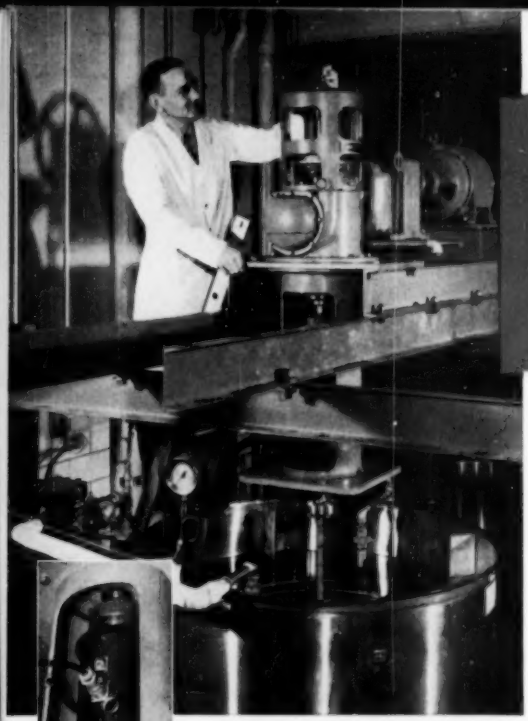

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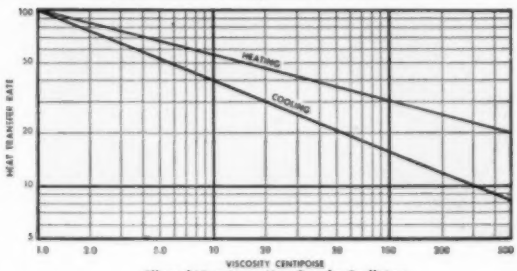
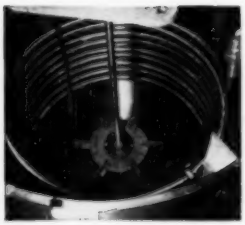


Effect of Viscosity on Heat Transfer Coefficient

Graph shows the effect of viscosity on heat transfer coefficient. Similar data or flow rate, vessel size and shape, impeller size, shape, location and other variables enable MIXCO Engineers to accurately specify heat transfer conditions for your particular process.



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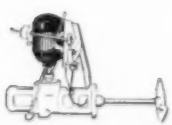

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